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June 1982
NDT Weld Quality Monitor/Semi-Automatic Welding

MICROPROCESSOR CONTROLLED WELD ARC SPECTRUM ANALYZER FOR QUALITY CONTROL AND ANALYSIS
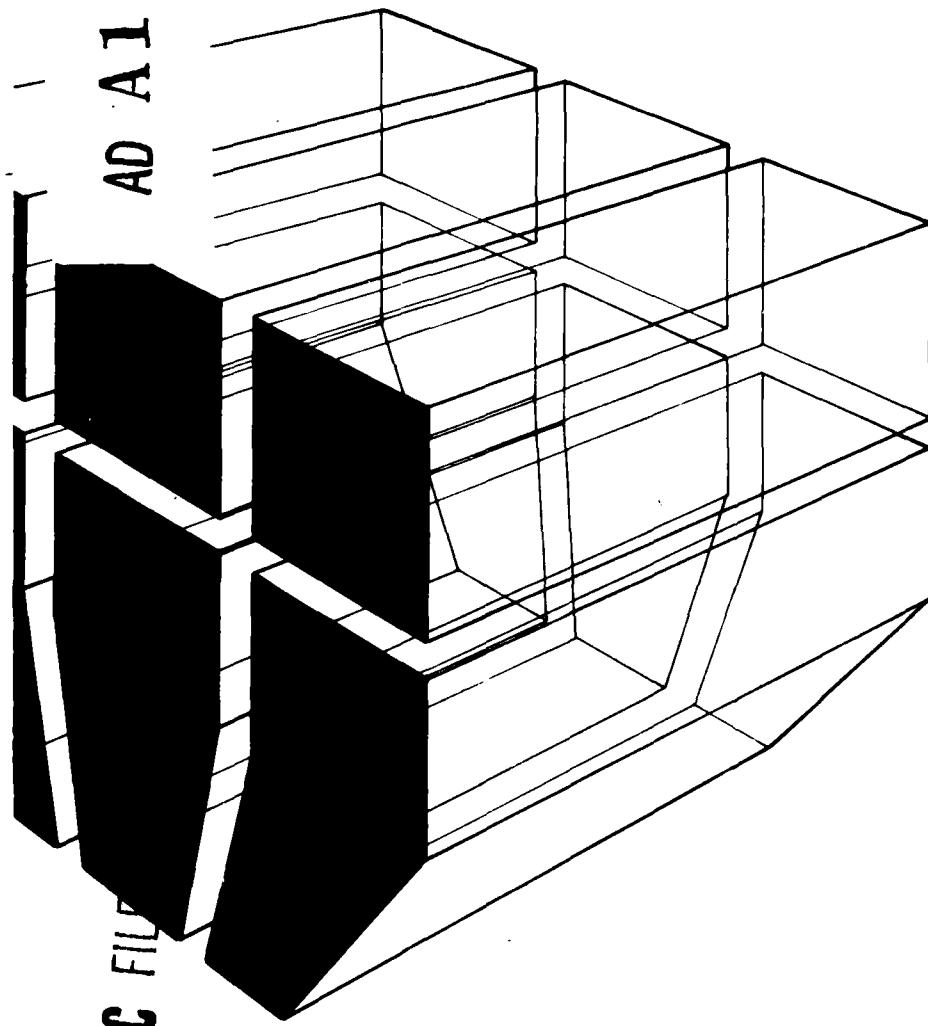
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This thesis describes the components and operation of a system designed to analyze parameters associated with a weld arc. In particular, the spectrum, voltage, current, and travel speed of the weld arc are sampled by a microprocessor for analysis.

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The system is broken down into hardware and software components, which are described in detail, and an operating procedure for the system is provided. Experimental results are given which correlate changes in the weld parameters with the occurrence of defects. Changes in the voltage and current of the arc are correlated with spectral changes of the arc. A correlation between the spectral energy and weld heat input is also presented.

FOREWORD

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Availability

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TABLE OF CONTENTS

DISTRIBUTION

5

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

During the welding process, changes in arc voltage, travel speed, heat input and shielding gas content can cause defects which seriously decrease the service life of the welded joint. The cost of locating and repairing these defects can be a major portion of the construction costs. During the past decade, the Construction Engineering Research Laboratory (CERL) has been developing a real-time weld quality monitor to detect flaws as they occur [1] - [3]. Recent work at CERL has indicated that it may be possible to detect weld flaws using electrooptical techniques. This paper describes a microprocessor controlled spectrograph for use with the CERL weld quality monitor.

Construction Engineering Research Laboratory engineers developed a low-resolution arc spectrum analyzer [2]. Photographic filters were used to divide the arc spectrum into five bands spanning the range from 400 to 1000 nanometers. With this device it was possible to separate and quantify segments of the weld spectrum and correlate the energy distribution among these segments to specific weld parameters. The results indicate that it may be possible to classify weld flaws based upon the energy distribution in the arc spectrum.

To supplement and extend this work, a high-resolution microprocessor-controlled spectrograph was developed. A block diagram of the system is illustrated in Figure 1. The optical radiation emitted by the weld arc in the region from 300 to 1200 nanometers is collected by a fiber optic bundle. The bundle, which is designed to withstand the higher temperatures surrounding the weld arc, is terminated at the spectrograph entrance slit. The light passing through the slit is reflected by a mirror to a concave holographic
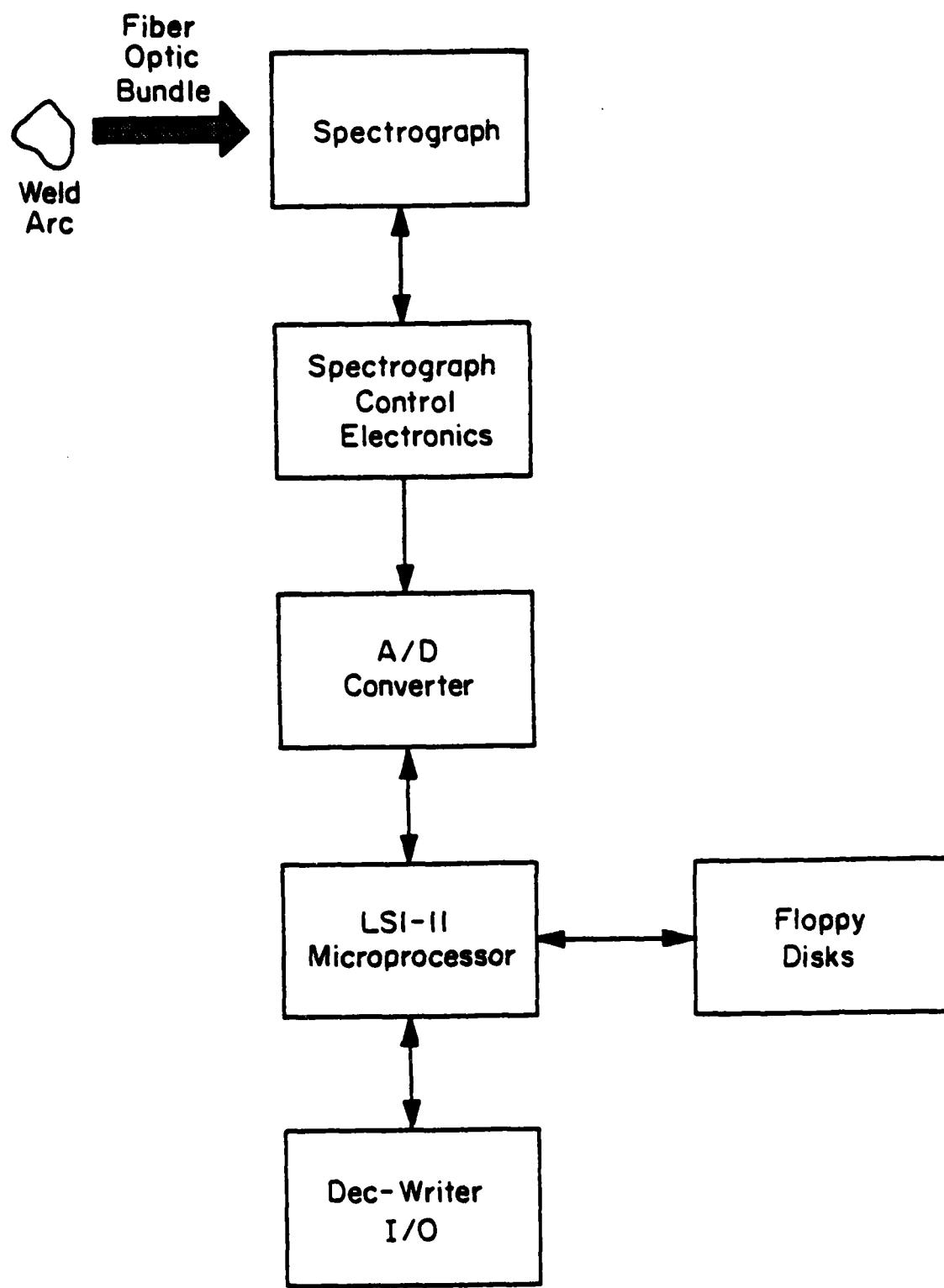
Figure 1. Block diagram of microprocessor controlled spectrograph.

grating which images the spectral range from 300 to 1200 nanometers onto a 1024 element linear photodiode array. The spectrograph resolution is on the order of 1 nanometer. The photodiode array is interfaced to a high-speed analog-to-digital converter and LSI 11/23 microprocessor. The spectral data along with measurements of the arc voltage, current, and travel speed can be processed or stored on floppy disks for later analysis.

With this system, important features of the weld arc can be observed in real time and correlated with weld flaws. This report describes in detail the system design and operation.

2. AN OVERVIEW OF THE WELD QUALITY MONITOR SYSTEM

The Weld Quality Monitor (WQM) is comprised of three parts: the optical and electronic hardware to measure the weld arc spectrum, the Digital Equipment Corporation (DEC) LSI-11 microcomputer for data acquisition and storage, and the software to control the WQM. The optical hardware is composed of a lens and fiber optic bundle that gathers the optical radiation from the weld and guides it to the spectrograph. The spectrograph uses a holographic grating to image the spectrum on a photo-diode array that is controlled by scanning and synchronization circuitry. Data are acquired by an analog-to-digital (A/D) converter that is controlled by Direct Memory Access (DMA) electronics. The user interface, data transfer, and WQM control are maintained by either Fortran IV or the DEC machine language, Macro-11. The device initialization, synchronization, and data acquisition programs are written in Macro-11. The user interface programs that are necessary for data specification and display are written in Fortran IV.

3. THE WELD QUALITY MONITOR SYSTEM

3.1 Spectrograph and Fiber Optics

3.1.1 Fiber optic bundle

The Dolan-Jenner fiber optic bundle is a steel clad industrial cable capable of withstanding 260 degrees centigrade (500 degrees Fahrenheit) temperatures (see Figure 2). It has an acceptance cone of 68 degrees and a numerical aperture of 0.55. Figure 3 [4] shows the transmittance curve for different lengths of cable. It is easily seen that the ultraviolet and middle infrared regions are severely attenuated. Fortunately, due to the high intensity of radiation emitted from the weld arc, signal strength can compensate for some of the losses.

3.1.2 Spectrograph

The spectrographs shown in Figures 4a and 4b have three different slit widths of 50, 100, and 250 µm. Light passes from the fiber bundle through the slit and strikes an ISA holographic grating. Either a 200-1200 nm or 200-800 nm range grating may be used. Using these slit widths and gratings produces the variation in resolution shown in Table 1. These are somewhat idealized results in that they neglect spillover into other diodes, parallax in alignment, and defocusing errors. Actual resolution may be as much as one nanometer worse than the values given.

TABLE 1

RESOLUTION OF SPECTROGRAPH

Slit Widths / Grating	50 µm	100 µm	250 µm
200-1200 nm	1.95 nm	3.91 nm	9.76 nm
400-900 nm	1.17 nm	2.34 nm	5.86 nm

15
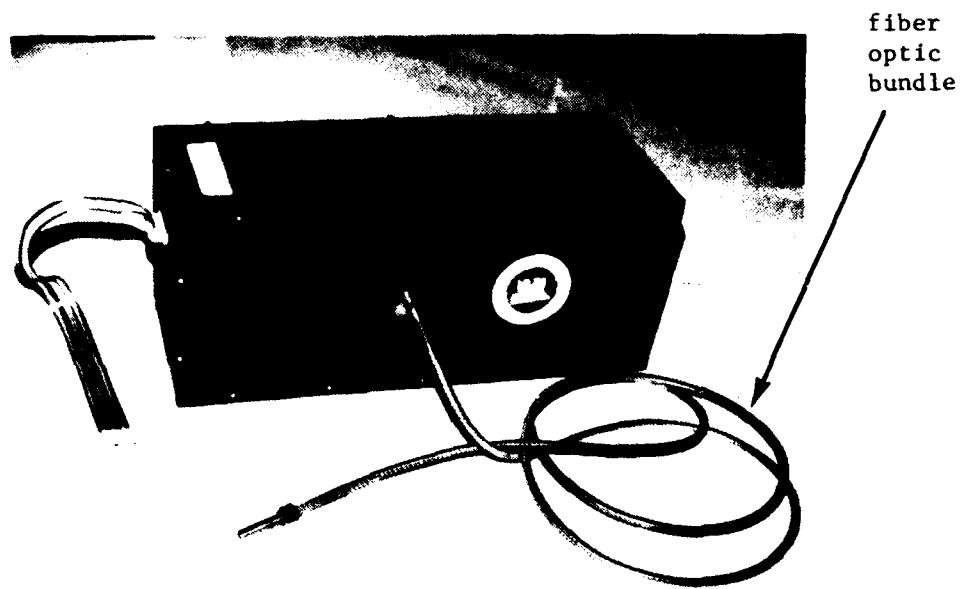
Figure 2. Fiber optic bundle to spectrograph.

TYPE X GLASS FIBER OPTIC TRANSMITTANCE

Fresnel Reflection 5.6 % / Surface
Core/Clad Ratio 82%
Packing Fraction 83%
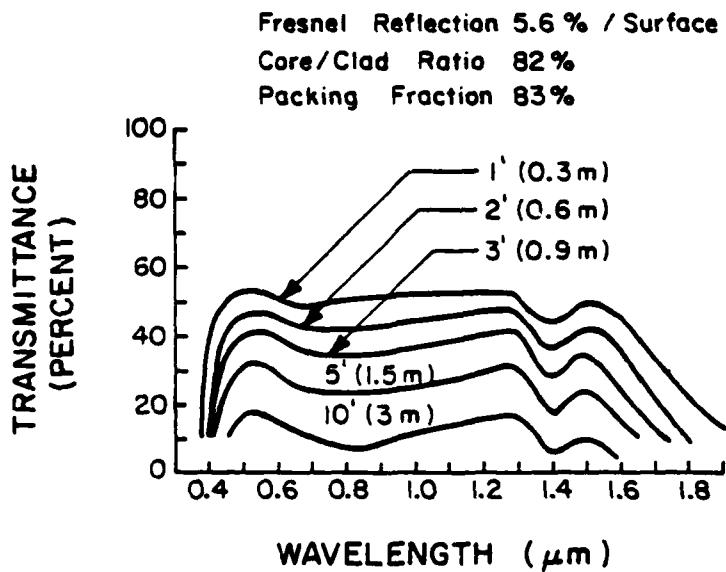
Figure 3. Transmittance curve for fiber bundle.

holographic
grating
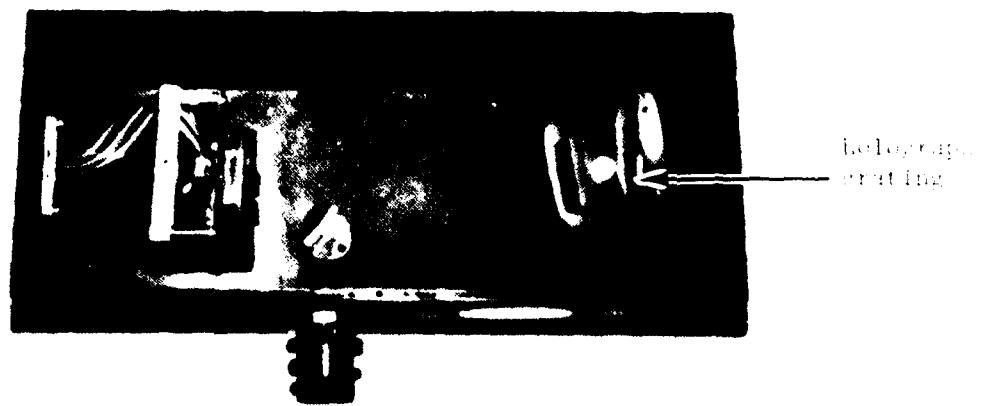
Figure 4a. Spectrograph (top view).

fiber optic
input
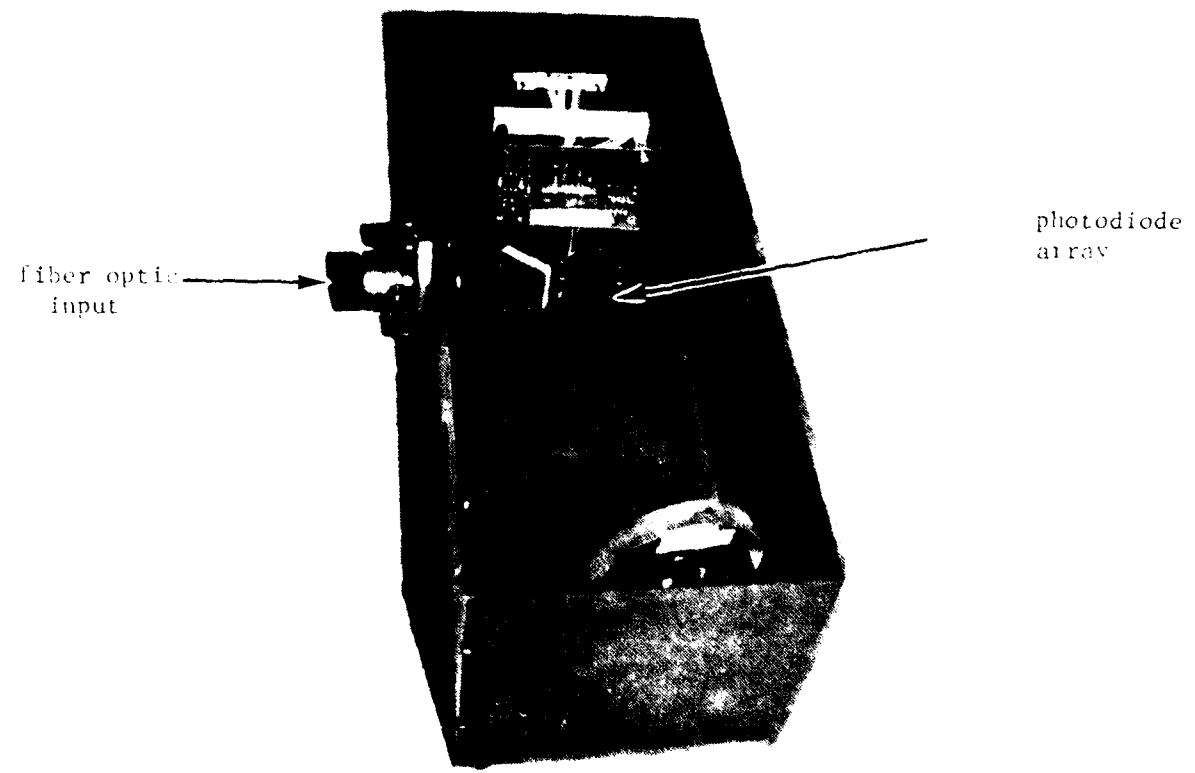
photodiode
array

Figure 4b. Spectrograph.

17

3.2 Photodiode Array and Electronics

The optical sensor consists of a 1.008-inch linear array of 1024 silicon photodiodes, 15 µm high, and 25 µm spacing. These dimensions are illustrated in Figure 5. Spectral responsivity, governed by the quartz window covering the array, the aperture response, and the quantum nature of the diodes themselves, decreases to about 20% at 250 and 1000 nm (see Figure 6).

Each diode has a storage capacitor for integration of the photo current. The charge on the storage capacitor is gradually removed by the reverse current generated by the photodiodes. Each capacitor is sequentially sampled by multiplex switches turned on and off by a shift register driven by a two-phase clock. At the end of each sample, the capacitor is recharged to +5 V. The clock sequence is initiated by a start pulse (see Figure 7).

The support electronics consist of sample and hold circuitry. The video line is set to ground prior to each diode sample. When a multiplex switch is closed, charge is divided between the photodiodes and the video line. This line is sampled and held, giving the display shown in Figure 8. The start pulse and clock (see Figure 9) are set by the user. Further details on this and other aspects of the array are contained in Appendix A.

Figures 10 and 11 show the oscilloscope displays of the spectral output of the electronics box in response to a Helium-Neon laser. Figure 10 shows the spectrum from 200 to 1200 nm. The wavelength of the radiation from a Helium-Neon laser is 632.8 nm. The display in Figure 10 verifies this. Figure 11 is an expanded display of the spectral line of the Helium-Neon laser. It shows that approximately three diodes are illuminated by the laser radiation. This corresponds to about 3 nm, which is as might be expected using the 50-micrometer slit on the spectrograph.
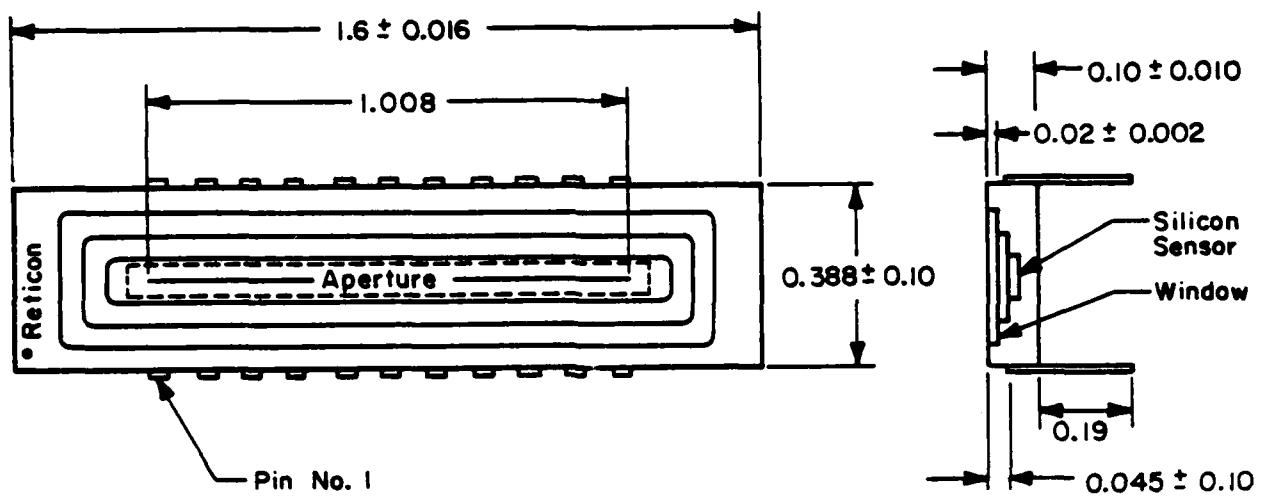
Figure 5. Photodiode array.

19
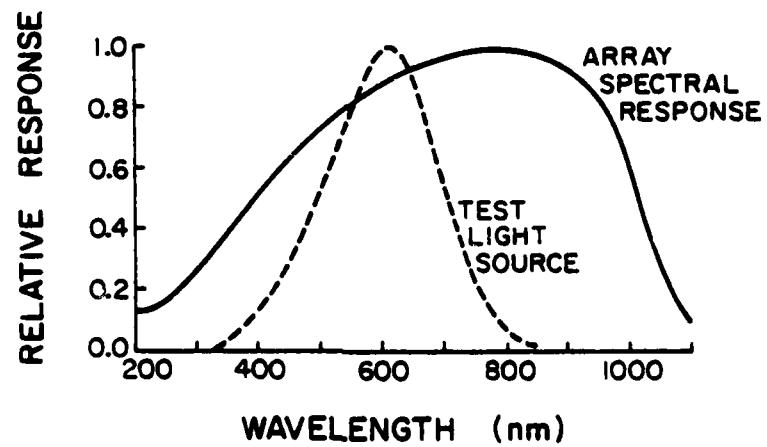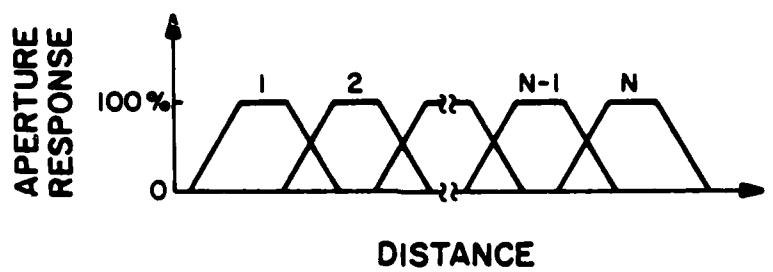
Figure 6. Optical response of photodiode array.
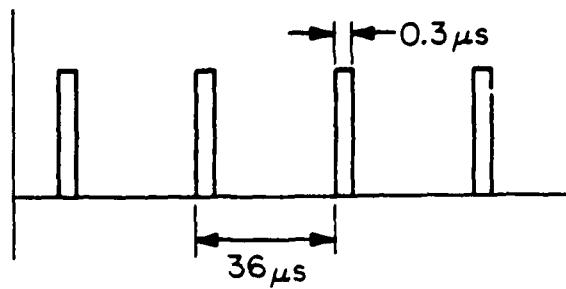
Figure 7. Start pulses.
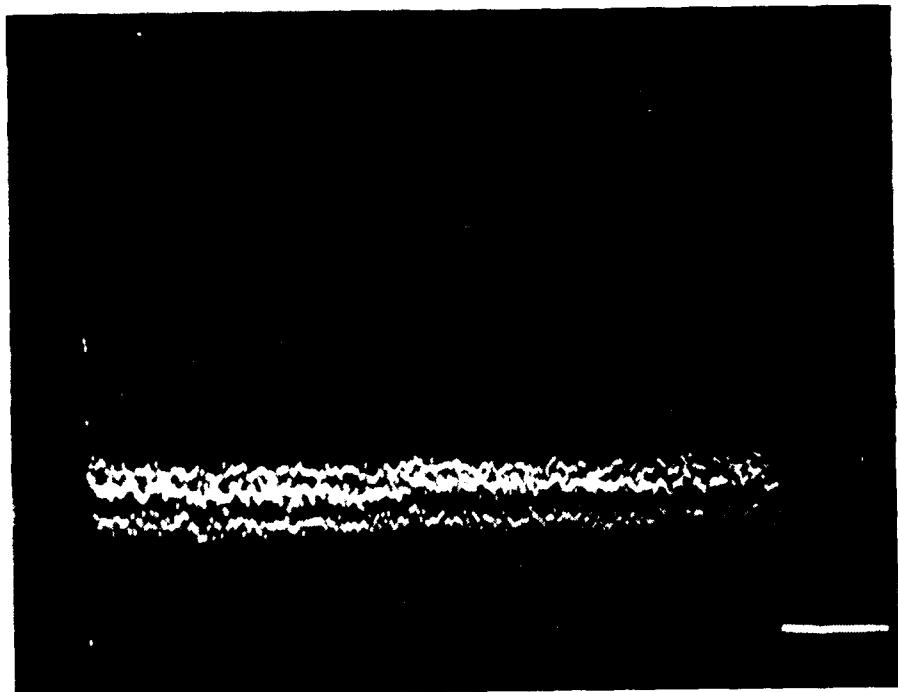
Figure 8. Video output.
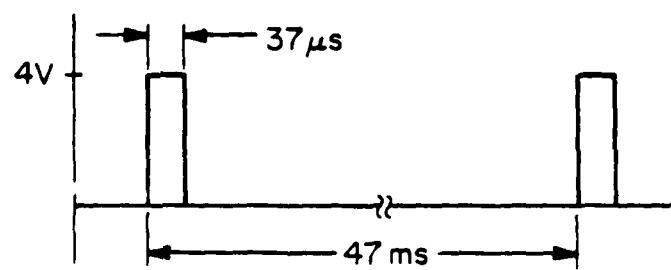
Figure 9. Clock pulses.

21
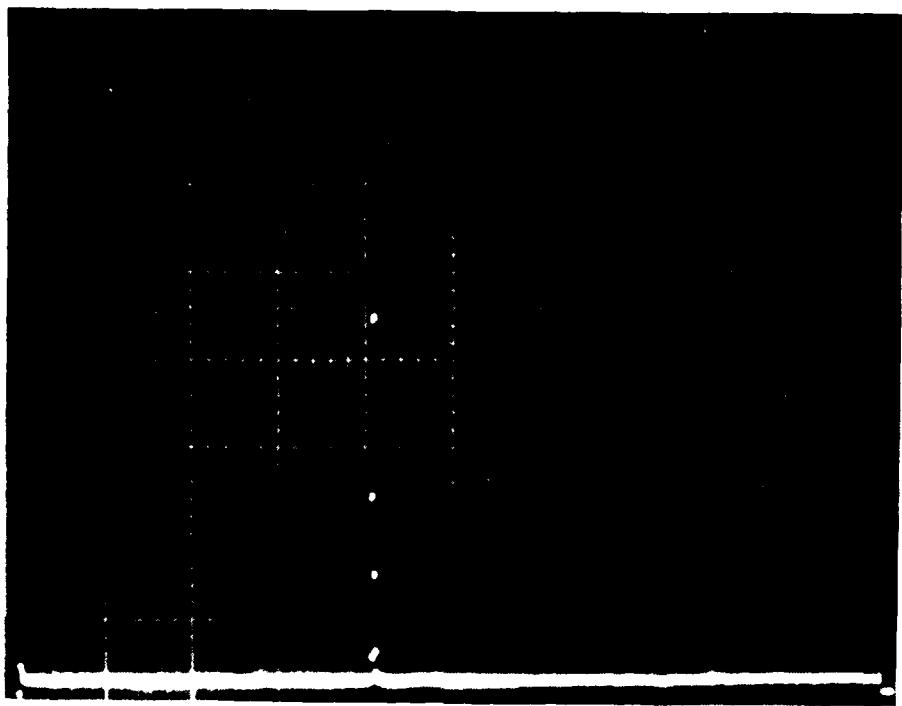
Figure 10.   Spectrum with Helium-Neon laser.
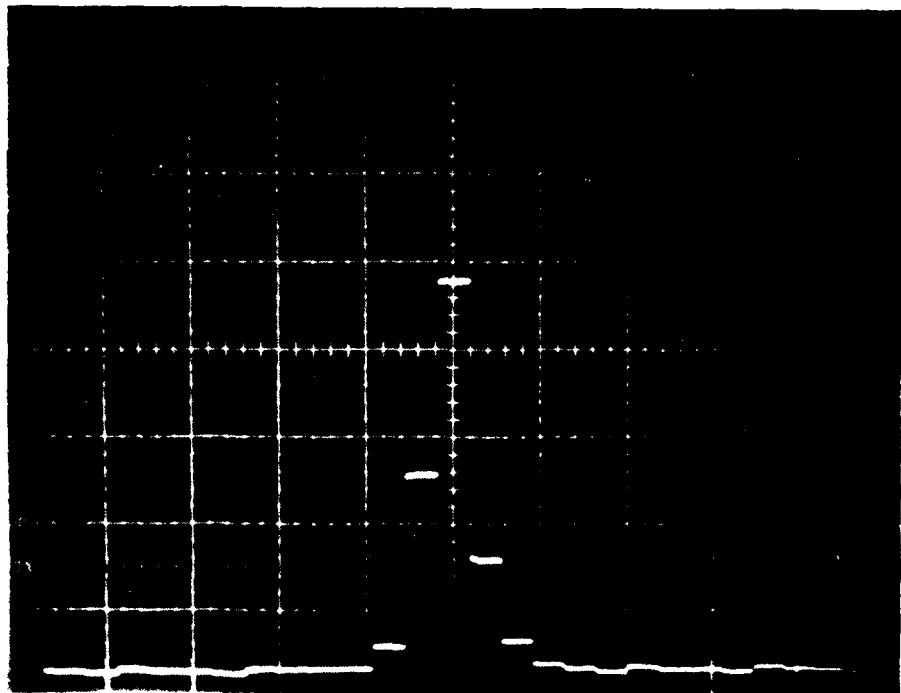
Figure 11.   Expansion of spectra showing individual diode levels.

The scanning electronics for the diode array run continuously. Thus, in order for the A/D to sample the diode levels accurately, synchronization circuitry must be provided, which is illustrated in Figure 12. The start pulse used to initiate the video scan sets a D flip flop. The D flip flop in turn opens a gate that allows the same clock pulses to be used by the A/D as an external enable. Thus the A/D is triggered synchronously with the video line out. The DMA has a word counter that is preset to 1024 so that sampling is terminated after all 1024 photodiodes are sampled. Figure 13 gives a timing diagram of the sequence of events.

3.3 LSI-11 Hardware Description

3.3.1 11/23 Central Processing Unit (CPU) description

The Digital Equipment Corporation (DEC) LSI 11/23 is a 16-bit word or 8-bit byte-oriented microprocessor. It is capable of executing over 400 machine language instructions. With the proper system software, it is further capable of handling Fortran, Pascal, APL, and Basic. The machine language utilized (Macro-11) is a stack-oriented language with eight general-purpose registers. Without extended software this language will directly access 64K words of memory. The lower 376 locations are reserved for interrupt vectors and traps. The top 8K works are reserved for peripheral device addressing. Further details on both the hardware and software associated with the 11/23 can be found in the DEC Microcomputer Processor Handbook [4].

3.3.2 Input/output description

3.3.2.1 Serial interface description. The serial interface for the LSI 11/23 is a DEC DLV11-J. It has four independent full duplex asynchronous channels capable of 150 to 9600 baud. Table 2 [5] indicates the jumper
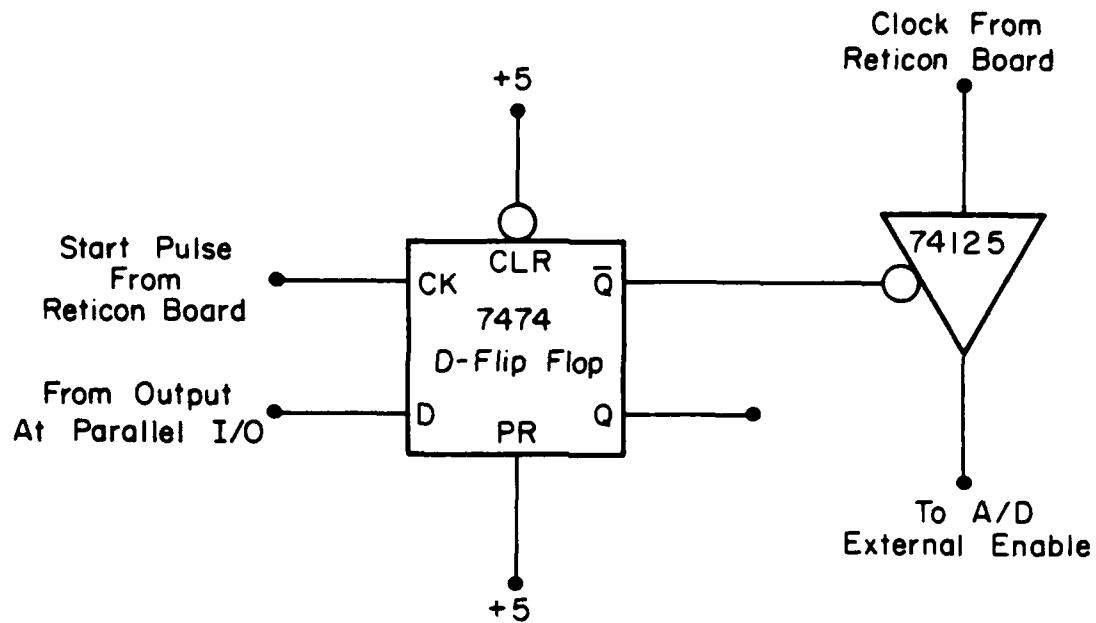
Figure 12. Synchronization circuitry.
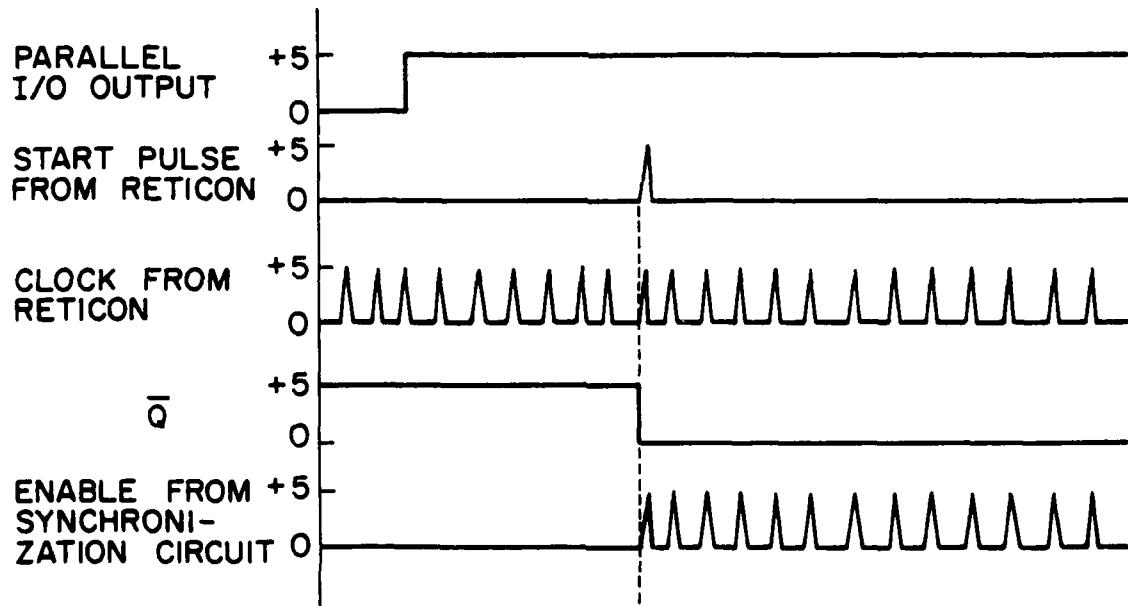
Figure 13. Timing diagram for synchronization.

24

TABLE 2

BAUD RATE JUMPERS [5]

Wire-Wrap Pin Label	Baud Rate (Bits/Second)
U	150
T	300
V	600
W	1,200
Y	2,400
L	4,800
N	9,600
K	19,200
Z	38,400

When using the DLV11-KA option, 110 bits/sec operation is possible. A 110 baud rate clock generator circuit on the option will supply the DLV11-J module with the proper clock; no baud rate jumper is configured on the module for the desired channel.

selections made on the DLV11-J to select the desired baud rate. Figure 14 [6] shows the location of the jumpers on the board.

Each channel is composed of a receiver control status register (RCSR), receiver buffer (RBUF), transmitter control status register (XCSR), and transmitter buffer (XBUF). The factory jumpered addresses for these channels are shown in Table 3 [6]. Further information on the DEC DLV11-J can be obtained in the DEC Microcomputer Interfaces Handbook, pp. 221-249 [6].

3.3.2.2 Parallel interface description. The parallel interface is an MDB MLSI-DRV11-C. It has sixteen TTL and DTL logic compatible input and output lines with four control lines for a peripheral device: NEW DATA READ, DATA TRANSMITTED, REQUEST A, and REQUEST B. Tables 4 [7] and 5 show the interface pin assignments and the addressing structure, respectively. Device address locations can be changed by utilizing the jumper selections shown in Table 6 [7]. Table 7 [7] shows the jumpers for selection of Interrupt Vectors. Figure 15 [7] shows the location of the jumpers on the module.

The Control Status Register (CSR) is a 16-bit word that is used to control the parallel I/O board. The bits in the CSR have the following functions:

BIT	NAME	DESCRIPTION
15	REQUEST B	A read only bit that is cleared by system initialization. This bit is set by a peripheral device and may be used as a flag for device status. It may also be used as an interrupt request if bit 5 is also set.
14-8	Unused	
7	REQUEST A	It has the same function as REQUEST B except the interrupt is generated only if bit 6 is set.
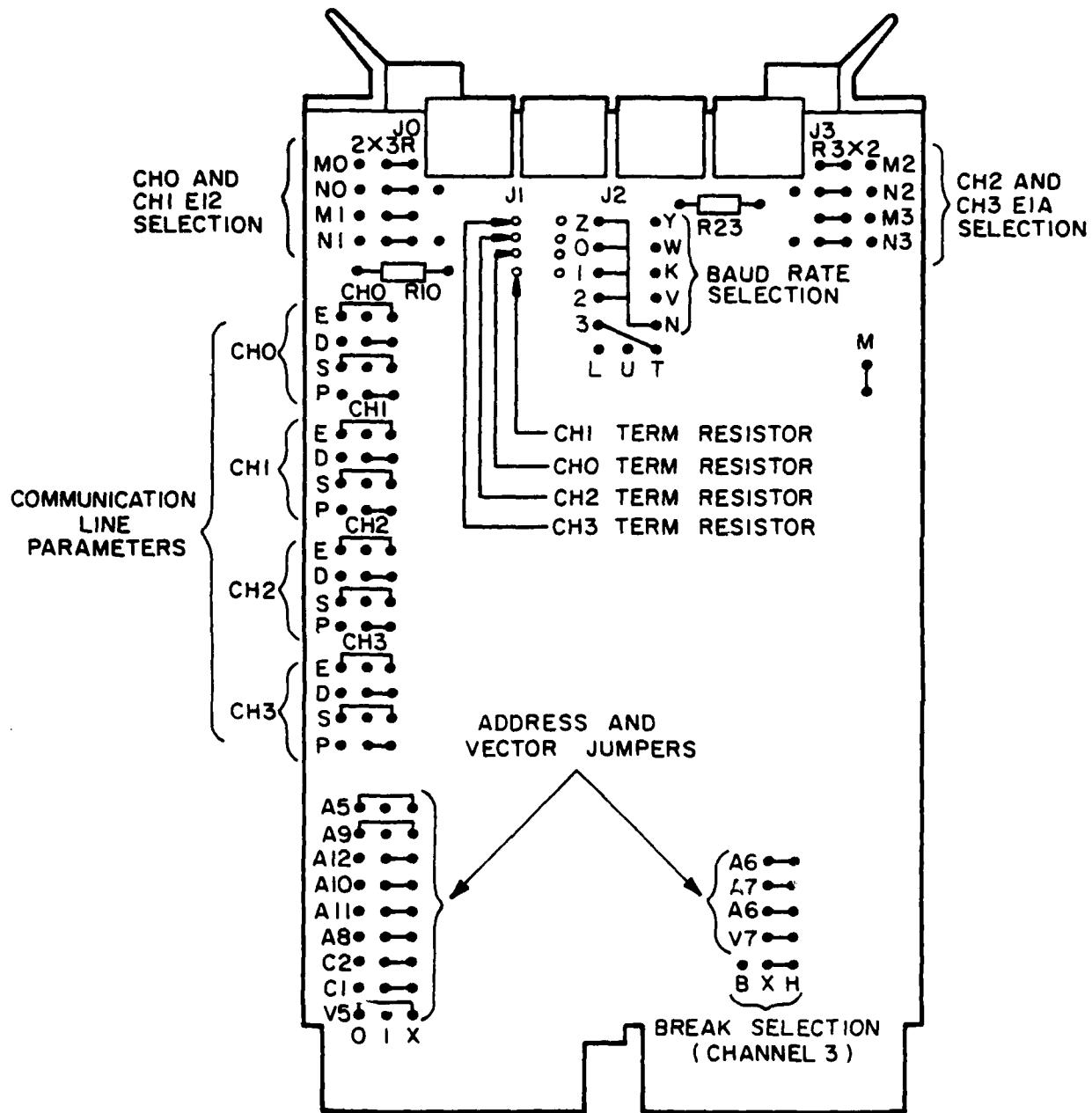
Figure 14.   Jumper locations on serial I/O board [6].

TABLE 3

CHANNEL ADDRESSES FOR SERIAL I/O BOARD [6]

Address	Register	Vector	
176500	RCSR		
176502	RBUF	300	
176504	XCSR		Channel 0
176506	XBUF	304	
176510	RCSR		
176512	RBUF	310	
176514	XCSR		Channel 1
176516	XBUF	314	
176520	RCSR		
176522	RBUF	320	
176524	XCSR		Channel 2
176526	XBUF	324	
177560	RCSR		
177562	RBUF	60	
177564	XCSR		Channel 3
177566	XBUF	64	

TABLE 4

INTERFACE PIN ASSIGNMENTS FOR PARALLEL I/O BOARD [7]

J1		J2	
Signal	**Pin**	**Signal**	**Pin**
OUT00	C	IN00	TT
OUT01	K	IN01	LL
OUT02	NN, RR	IN02	H. E
OUT03	u	IN03	BB
OUT04	L	IN04	KK
OUT05	N	IN05	HH
OUT06	R	IN06	EE
OUT07	T	IN07	CC
OUT08	W	IN08	Z
OUT09	X	IN09	Y
OUT10	Z	IN10	W
OUT11	AA	IN11	V
OUT12	BB	IN12	u
OUT13	FF	IN13	P
OUT14	HH	IN14	N
OUT15	JJ	IN15	M
INIT	P	INIT	RR. NN
NEW DATA READY	VV	DATA TRANSMITTED	C
CSRI	DD	CSRO	K
REQUEST A	LL	REQUEST B	S
GND	J. M. S. V. CC. FF. KK. MM. PP. SS. UU	GND	J. L. R. T. X. AA. DD. JJ. MM. PP. SS. UU

TABLE 5

ADDRESSING STRUCTURE FOR PARALLEL I/O BOARD

Address Name	Mnemonic	Address
Control Status Register	CSR	167770
Output Buffer	OUTBUF	167772
Input Buffer	INBUF	167774

TABLE 6

DEVICE ADDRESS JUMPERS FOR PARALLEL I/O BOARD [7]

Address Bit	Jumper Location	Connect for "1"	Connect for "0"
12	4	K-J	H-J
11	5	N-M	L-M
10	5	H-J	K-J
09	3	N-M	L-M
08	2	L-M	N-M
07	1	H-J	K-J
06	4	L-M	N-M
05	3	K-J	H-J
04	2	H-J	K-J
03	1	L-M	N-M
02	Bits 00, 01, and 02 are hardwired		
01	and program-controlled.		
00			

TABLE 7

INTERRUPT VECTOR ADDRESS JUMPERS FOR PARALLEL I/O BOARD [7]

Address Bit	Jumper Location	Connect for "0"	Omit for "1"
07	6	H-J	H-J
06	8	H-J	H-J
05	9	H-J	H-J
04	10	H-J	H-J
03	7	H-J	H-J
02	none	hardwired	
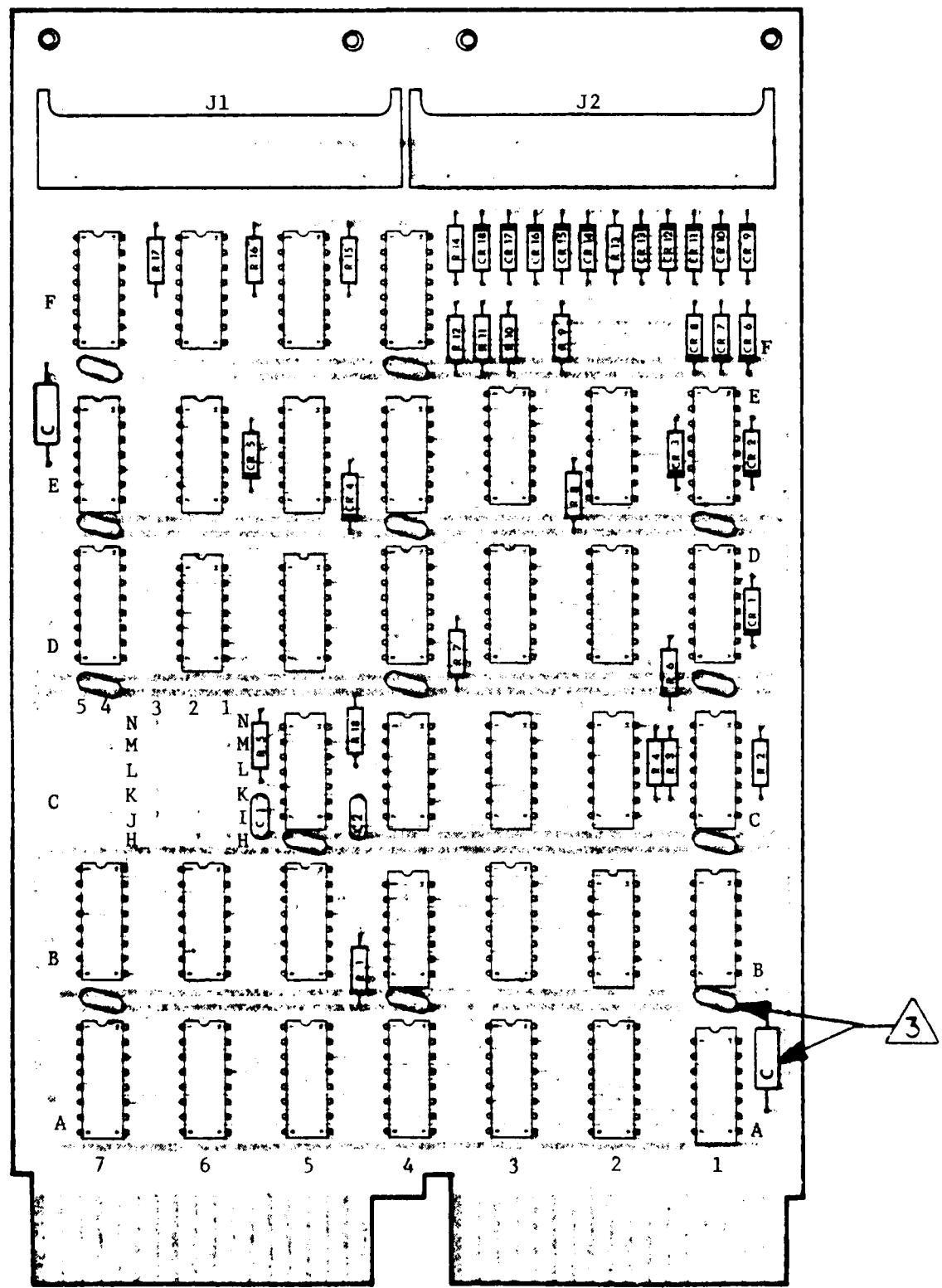
Figure 15. Jumper locations on DRV11-C [7].

BIT	NAME	DESCRIPTION
6	ENTENBA	A read/write bit cleared by system initialization. When set, it will enable an interrupt to occur upon the setting of bit 7.
5	INTENBB	It has the same function as bit 6 except it applies to bit 15. Cleared by system initialization.
4-2	Unused	
1	CSR 1	A read/write bit cleared by system initialization. It can be used to flag a device.
0	CSR 0	Same as bit 1.

More information can be obtained from the MDB MLSI-DRV11C Parallel Line Interface Module Instruction Manual [6].

The DRV11C is used to synchronize the A/D converter with the video line from the Reticon scanning electronics. By moving a 1 into the output buffer, pin C is set on the output cable. This line is then tied to the input of a D flip flop that opens a gate at the occurrence of a start signal from the array scanning electronics that initiate scanning. When the gate opens, it allows the video clock signal to trigger the A/D converter.

3.3.3 Floppy disk description

The floppy disk control module is a DEC RXV21 (see Figure 16) board that controls a dual density RX02 floppy disk drive (see Figure 17). Each floppy disk is capable of storing 512,512 eight-bit bytes per diskette. The average access time (composed of seek, settle, and rotate time) is 262 msec. Additional details on the operation of the RXV21 with the RX02 drive can be found in the DEC Microcomputer Interfaces Handbook, pp. 608-628 [6].

Floppy disk files can be accessed for reading or writing either manually or under program control. The system provides two methods for user interactive editing of disk files. The RT-11 editor provides a simple but
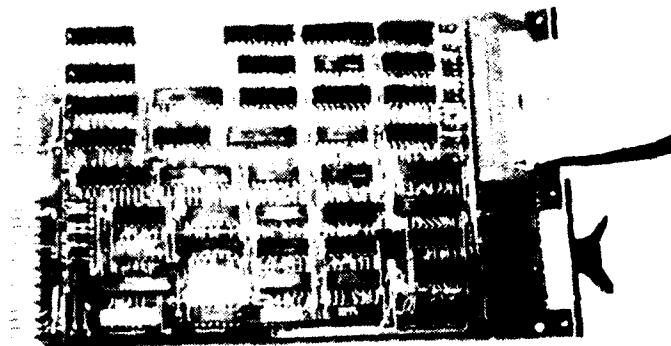
Figure 16. RXV21 floppy disk board.
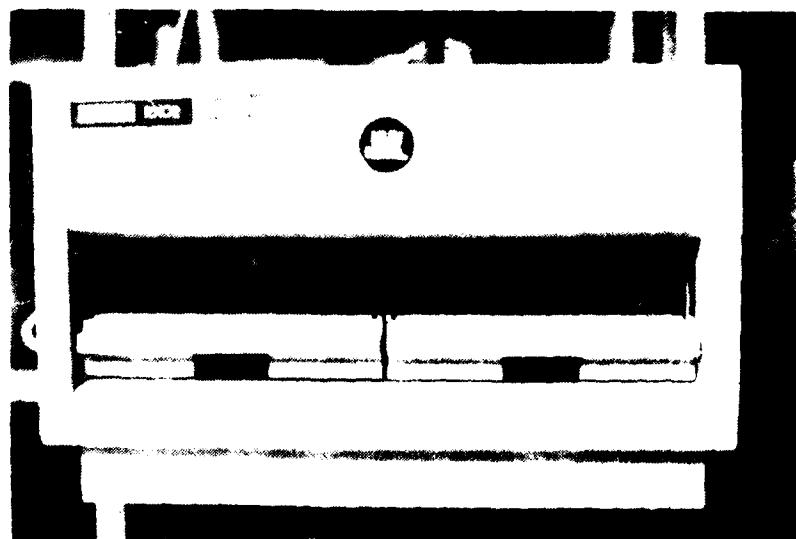
Figure 17. RX02 floppy disk drive.

unsophisticated means for editing disk files. An easy-to-read, step-by-step introduction is provided in volume 1B, "Introduction to RT-11," Chapter 5, "Creating and Editing Text Files," of the RT-11 Operator Manuals [8]. A more sophisticated method of editing files is provided by using TECO (Text Editor and Corrector). Unlike the RT-11 editor, TECO is character-oriented rather than line. Thus, it provides the user with better scanning software. A complete guide to TECO is provided in the "TECO Users Guide," volume 2 of the RT-11 Operator Manuals [8].

There are three other methods of writing and reading files on floppy disks. The crudest of these three is done using macros. It has, however, the advantage of using less space for program storage and of being faster. Chapter 2 of the "Advanced Programmer's Guide," volume 3 of the RT-11 Operator Manuals [8], describes the program requests available. The other two methods are accessed as RT-11 Fortran subroutines. Unfortunately, in order to understand the subroutine available, a good understanding of the macro program request is essential. The Fortran system subroutine library contains the necessary routines needed to allocate channels, name devices, etc. A combination of all these subroutines is contained in two subroutines called OPEN and ASSIGN. They are very sophisticated and require a good understanding of the Fortran system subroutines from which they are built. A description of these two commands can be found in Appendix B of the "Fortran User's Guide," volume 4 of the RT-11 Operator Manuals [8].

3.3.4 Analog to digital converter

The A/D converter is an ADAC Model 1012 (see Figure 18) [9]. It has 16 single-ended, pseudo difference, or differential inputs. Each line has programmable gain, 100 KHz throughput (10 microsecond settling and conversion

34
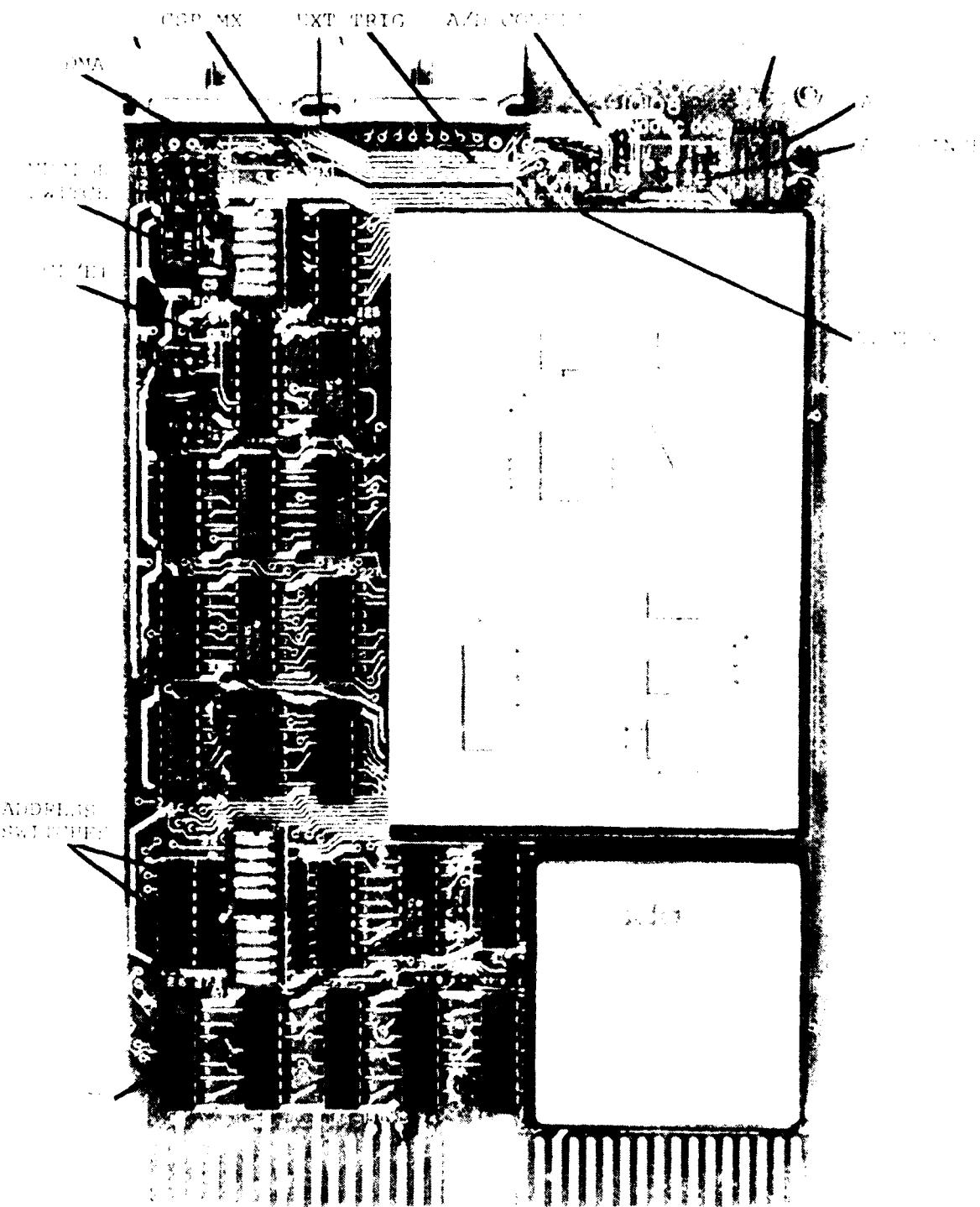
Figure 18. Jumper and adjustment locations on A/D [9].

time), and 12-bit resolution. Nine optional hard jumpered features on the A/D are the input range, type of input configuration, trigger, status register, external enable, vector, external trigger, DMA, and external power. All of these jumpered options are discussed in the ADAC Instruction Manuals, pp. 27-28 [9]. Presently, the board is configured for a -10 to +10 voltage input range, single-ended input, external triggering, bit 1 as the external enable in the CSR, DMA control disabled (so triggering is done externally), and no external power.

Switch jumpers are provided for selection of the control status register and vector interrupt location. These switches are set up as illustrated in Figure 19 with an off setting as a one and an on setting as a zero. The current control status register and vector address are 177000 and 130, respectively.

Input and output are done over a 20 conductor shielded ribbon cable. Pin assignments for the ribbon cable's connector are given in Figure 20. Currently, channel 0 is used for the video signal, channel 1 for the voltage, channel 2 for the current, and channel 3 for the travel speed. The external trigger is supplied by the synchronization circuitry and Reticon electronics. Further details on cabling can be found in the ADAC Instruction Manuals, pp. 14-15 [9].

Control of the A/D is maintained through the status register. It is set up as follows:

	1	ON	D7	1	OFF	D12	1	ON	D7
	2	ON	D6	2	OFF	D11	2	OFF	D6
	3	ON	D5	3	OFF	D10	3	ON	D5
	4	ON	D4	4	OFF	D9	4	OFF	D4
	5	ON	D3	5	ON	D8	5	OFF	D3
							6	ON	D2

S1   S2   S3

ADDRESS SWITCHES   VECTOR SWITCH
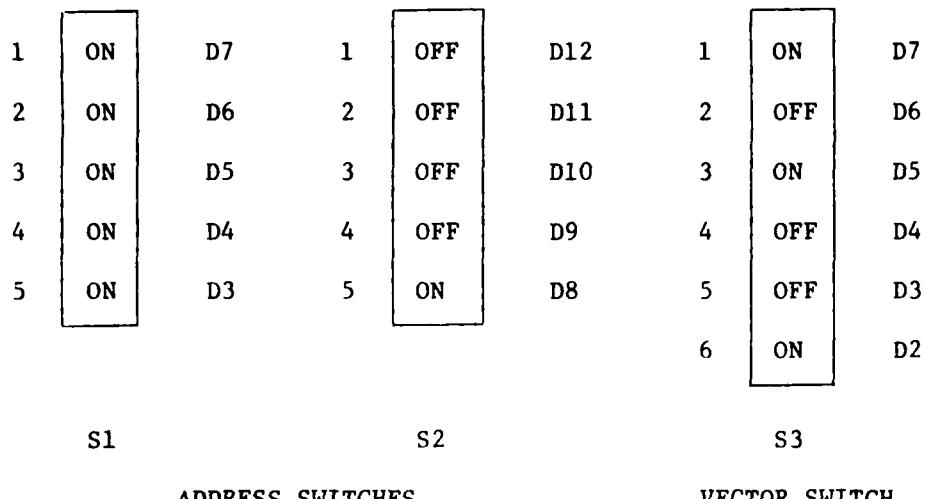
Figure 19. Jumper switches for addressing for 1012 A/D.

CANON PIN NUMBER	3M PIN NUMBER		CANON PIN NUMBER	3M PIN NUMBER	
1	1	CH0-0A IN	20	2	CH8-0B IN
2	3	CH1-1A	19	4	CH9-1B
3	5	CH2-2A	18	6	CH10-2B
4	7	CH3-3A	17	8	CH11-3B
5	9	CH4-4A	16	10	CH12-4B
6	11	CH5-5A	15	12	CH13-5B
7	13	CH6-6A	14	14	CH14-6B
8	15	CH7-7A	13	16	CH15-7B
9	17	EXT TRIG IN	12	19	POWER RETURN
10	19	AMP LO IN	11	20	SIGNAL RETURN

Figure 20. Pin assignments for I/O on ADAC 1012 A/D.

BIT	DESCRIPTION
D15	ERROR (Read Only). Set if a conversion is started before a previous conversion is completed or before data are removed from the data buffer.
D14	ERROR INTERRUPT ENABLE (Read/Write). When set, allows an interrupt at selected vector upon setting of D15.
D13, D12	Unused.
D11-D8	MUX CHANNEL (Read/Write). 4-bit channel number corresponding to the channel to be converted.
D7	DONE (Read Only). Set at end of conversion. Cleared by system initialization or reading of data buffer.
D6	DONE INTERRUPT ENABLE (Read/Write). When set, allows DONE to generate an interrupt at chosen vector.
D5	OPTIONAL ENABLE (Read/Write). Optional external enable.
D4, D3	PROGRAMMABLE GAIN (Read/Write). Two-bit gain code.

Gain Code	Gain
0	8
1	4
2	2
3	1

BIT	DESCRIPTION
D2	SEQUENTIAL ENABLE (Read/Write). Will allow the mux channel register to be incremented after a conversion for each channel.
D1	EXTERNAL ENABLE (Read/Write). A'lows an external signal to start a conversion.
D0	START CONVERSION (WRITE ONLY). Starts a conversion.

Thus, a simple move instruction can be used to initialize the A/D board. The data buffer for the A/D is located 2 bytes after the CSR or at 177002 in this case. It is a read-only register.

Appendix B provides complete schematics for the ADAC 1012 and a calibration procedure. Complete details on the board can be found in the ADAC Instruction Manuals, pp. 9-41 [9].

3.3.5 Direct Memory Access description

The ADAC Model 1620 Direct Memory Access (DMA) is a DEC compatible board that provides a means of transferring digitized data directly from the ADAC A/D to memory, without CPU intervention. It has an 18-bit memory address counter, a 6-bit final channel register and comparator, a 16-bit word counter, and interrupt enable capability. The DMA is composed of four registers which are described as follows (addressing is described in Table 8):

1) Bus Address Register (BAR): an 18-bit read/write register that is loaded under program control. The BAR is incremented by two after each DMA transfer. This address is used to specify the address in memory to which the data are to be moved. It is word addressable only.

2) Word Count Register (WC): a 16-bit read/write register that contains the 2's complement of the total number of cycles to be completed before DMA termination. It is also loaded under program control. WC is incremented after each DMA transfer, and upon overflow, resets READY FF in the Control Status Register and causes an interrupt request. It is word addressable only.

3) Multiplex Comparator Register (MCR): a six-bit write only register that is loaded under program control. It is used for last channel addressing when used in conjunction with the 1012 A/D. It is word addressable only.

4) Control and Status Register: a 16-bit register that is used to control the DMA. It is broken down as follows:

39

TABLE 8

ADDRESSING STRUCTURE OF DMA

Register Name	Mnemonics	Address
Word Count Register	WC	172410
Bus Address Register	BAR	172412
Control and Status Register	CSR	172414
Multiple Comparator Register	MCR	172416

BIT	DESCRIPTION
D15	ERRORS (Read Only). Set by addressing nonexistent memory or by grounding of external ATTN line. Cleared by system initialization, the clearing of D14, or clearing ATTN line.
D14	NEX (Read/Write). Nonexistent memory (NEX) is set by addressing nonexistent memory.
D13	ATTN (Read Only). Indicates status of ATTN line.
D12-8	Not used.
D7	READY (Read Only): Indicates DMA is ready to start a new set of data transfers. Set by system initialization, word count overflow, and clearing of ERROR (D15).
D6	INTERRUPT ENABLE (Read/Write). Enables interrupts when READY (D7) is set. Cleared by system initialization.
D5, D6	Extended Address Bits-17,16 (Read/Write).
D1-3	Not used
D0	GO (Write). Starts DMA operation. Forces READY (D7) to go low.

Complete schematics for the ADAC 1620 DMA are given in Appendix C.

Further documentation for the DMA can be found in the ADAC Instruction

Manuals, pp. 42-50 [9].

3.4 LSI-11 Software Description for the WQM

3.4.1 Fortran program

The Fortran program, AQSPEC (see Appendix E), is an operator interface

that leads the Weld Quality Monitor operator through a sequence of questions

to qualify and quantify the nature of the data desired. It also allows the

operator the opportunity to examine acquired data. A flowchart of the pro-

gram and a flowchart of the program as the user sees it are given in

Figures 21 and 22, respectively. The user is queried whether a single or

average set of scans is to be taken. If a single scan is desired for
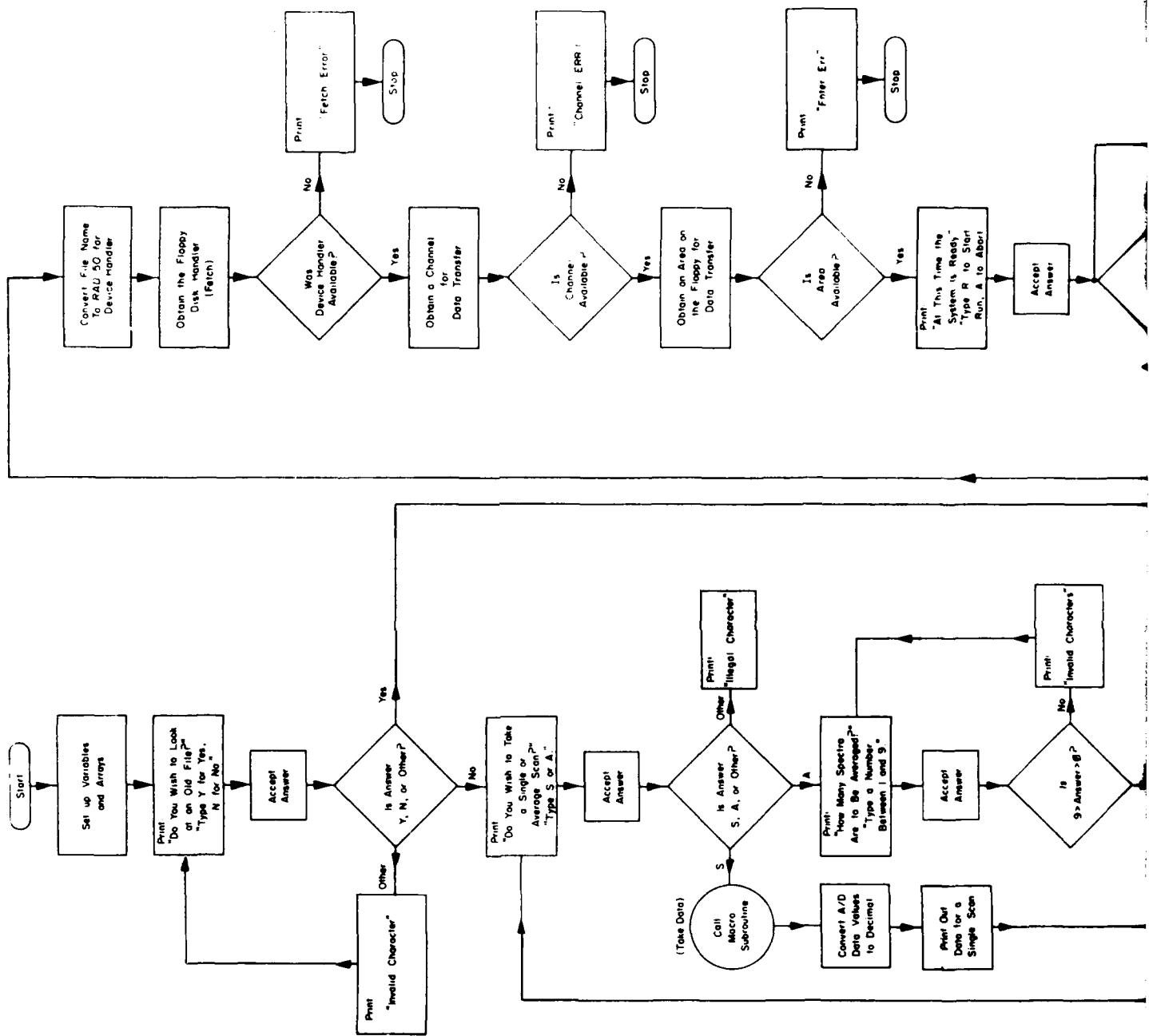
Figure 21.   Flowchart of FORTRAN program.

43

Flowchart of FORTRAN program.

43
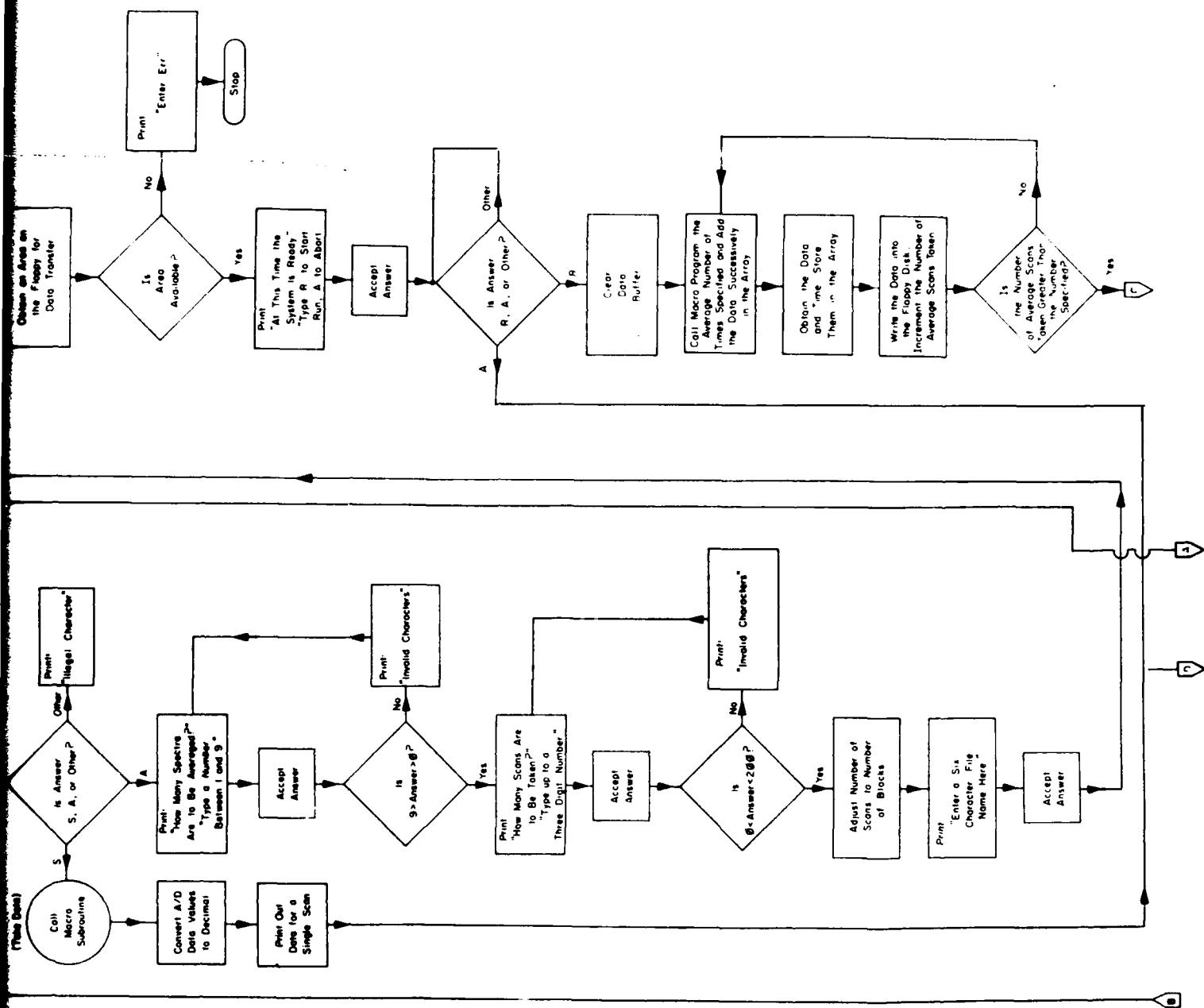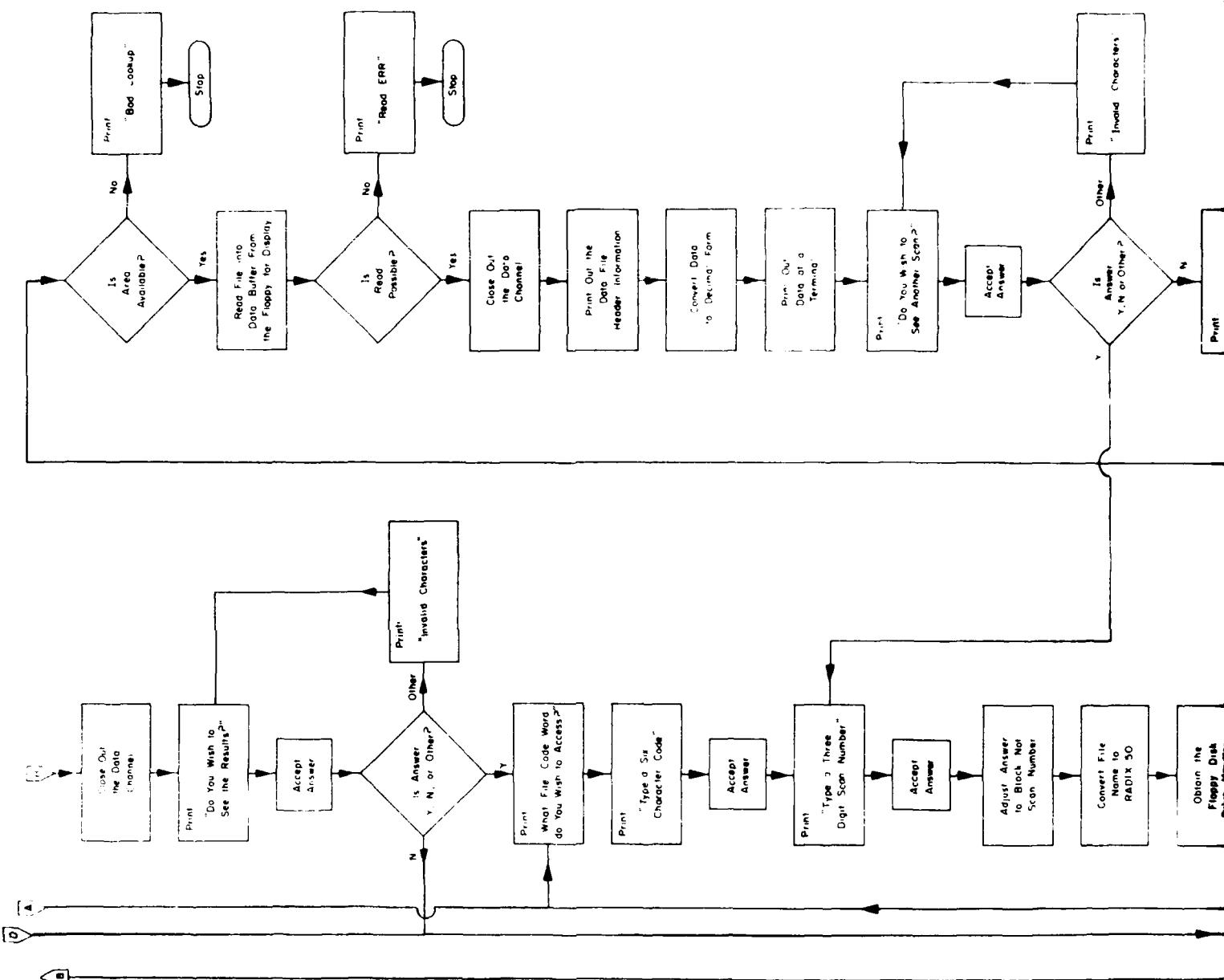
Figure 21. Continued.

45

. Continued.

43
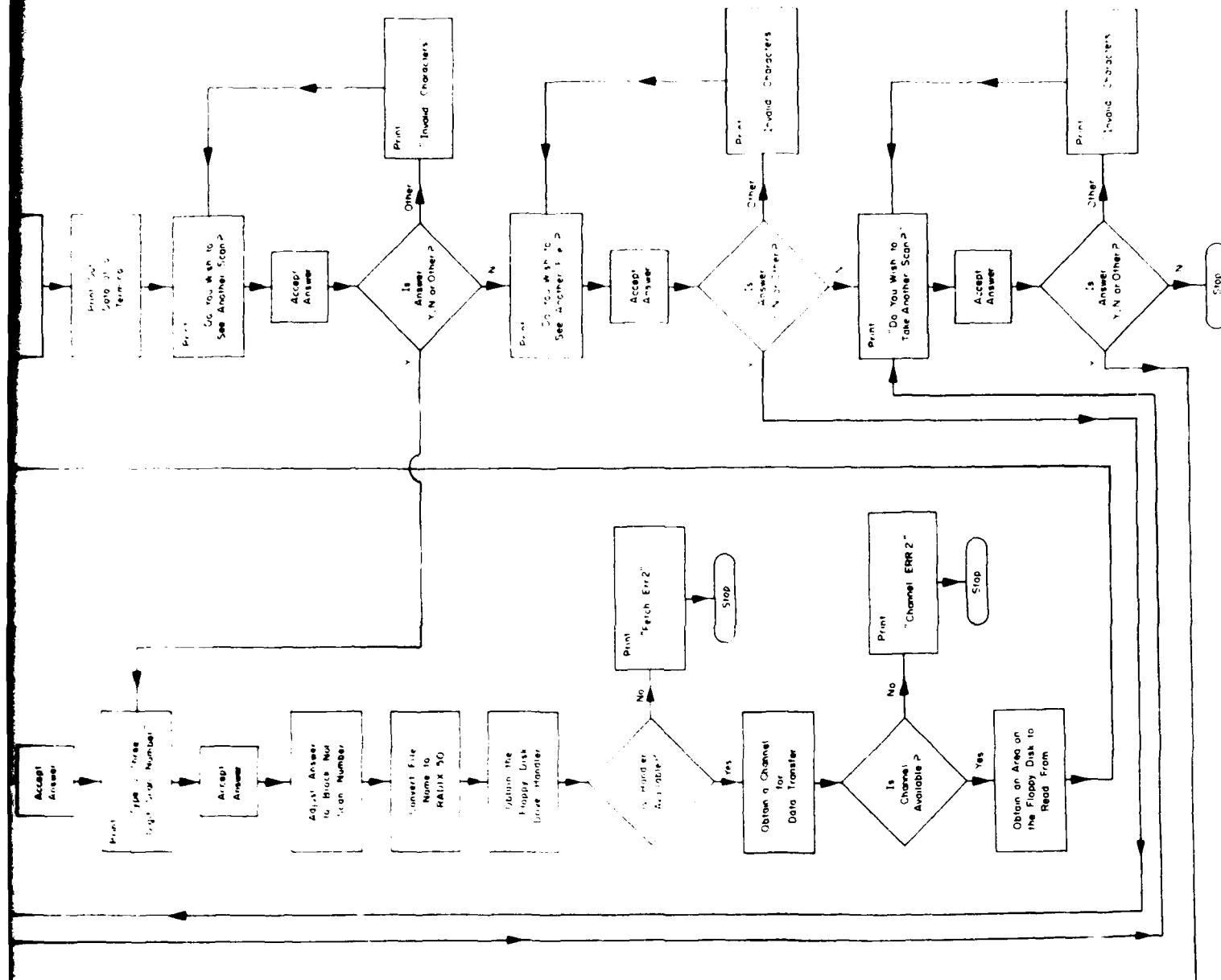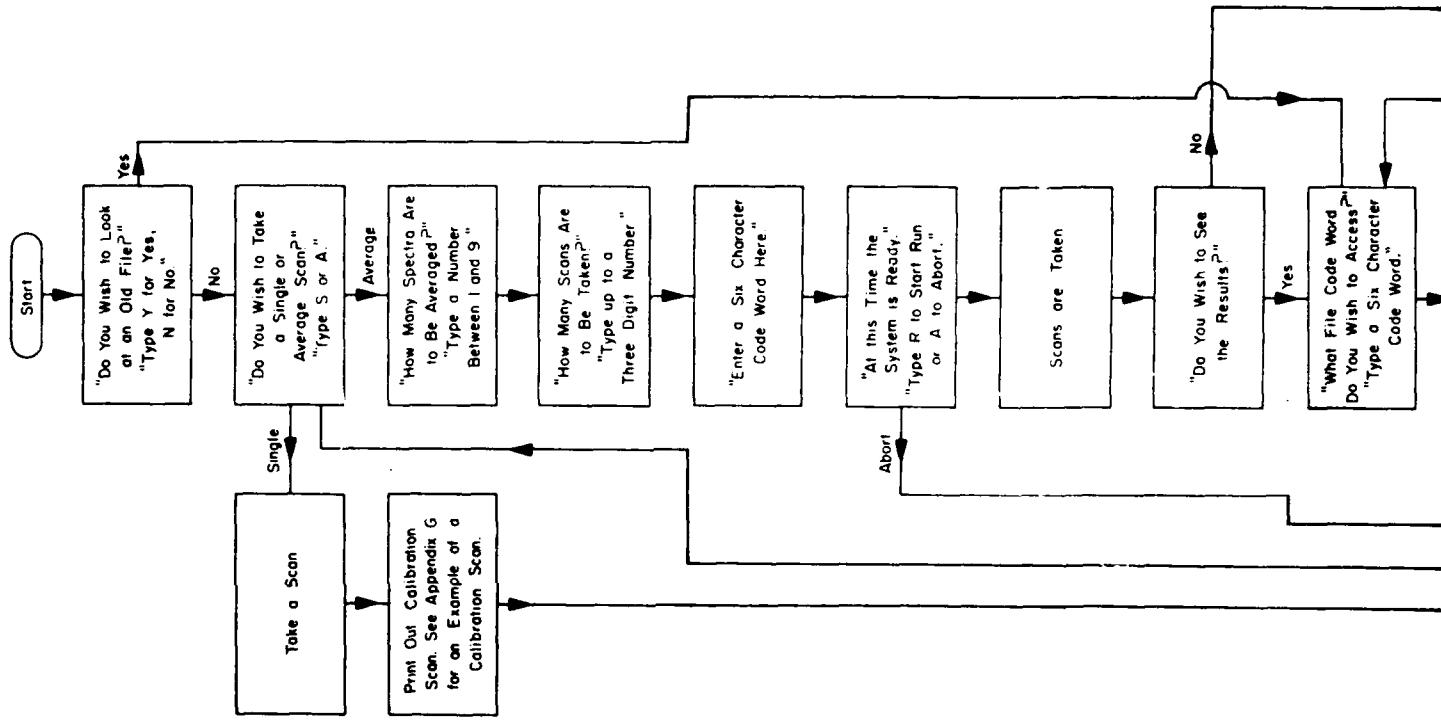
Figure 22.   User flowchart of FORTRAN program.
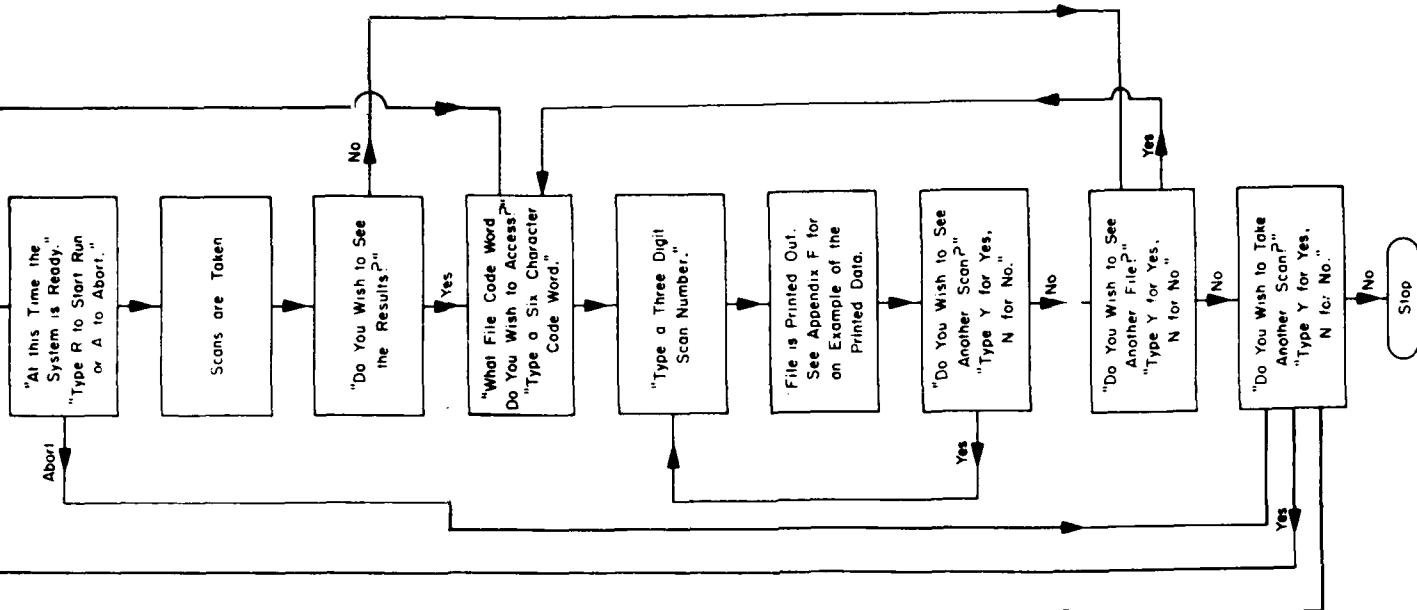
User flowchart of FORTRAN program.

calibration, a call to DMAIT (the Macro-11 subroutine for data collection, see next section) is made. If actual data are to be taken, then an average scan is selected. The user must select the number of spectral scans that the user wishes to have averaged together. Then, the user specifies the total number of these averages that the user wishes to store and thereby sets the amount of time used for data acquisition. It takes, on the average, 0.26 second for the head on the floppy disk drive to search and settle on the floppy disk and 0.15 second to acquire, add, and write a spectral scan. Thus, it takes about 1 second to acquire 5 scans, add them, and store them on the disk. For the sake of expediting data acquisition, the voltage levels taken from the A/D are added together and stored as a sum. Division by the number of scans is done when the data are outputted onto a peripheral device.

Data storage on floppy disks is accomplished through a set of Fortran subroutines available with the RT-11 Fortran Library. These routines are described extensively in the RT-11 Operator Manuals, vol. 3, "Advanced Programmer's Guide" [8]. Each file that is created on a floppy disk under the RT-11 system is catalogued with a user-defined file name and its subsequent creation date. The file, as it is created in AQSPEC, is sub-divided into sets of 1024 words. The first 11 words are used to store the date the data were taken, approximate time the data were taken, number of scans averaged, arc voltage, arc current, and travel speed. Thus, the first 11 photodiode voltage levels are overwritten. However, the next 1013 are intact.

Values stored directly from the A/D are not equal to the actual voltages at the A/D input channel ports. The voltage conversion specified by ADAC is given as follows.

If the range is unipolar, look up the proper conversion factor from Table 9 [9] and utilize the formula (1) shown below.

$$\text{Voltage(decimal)} = \text{Conversion Factor(decimal)} \times \text{A/D Output(decimal)} \quad (1)$$

If the range is bipolar, there are two separate procedures for negative and positive voltages. For negative voltages, or decimal A/D values less than 4095 and greater than 2046, find the proper conversion factor from Table 9 [9] and utilize formula (2) shown below.

$$\text{Voltage(decimal)} = -\text{Conversion Factor(decimal)} \times [4095 \text{ A/D Output(decimal)} + 1]$$
$$(2)$$

For positive bipolar voltages or decimal values less than 2046 and greater than zero, find the proper conversion factor and utilize formula (3).

$$\text{Voltage(decimal)} = \text{Conversion Factor(decimal)} \times [\text{A/D Output(decimal)} + 1]$$
$$(3)$$

Individual arc spectra with the accompanying time, date, arc voltage, current, and travel speed can be displayed on the LA120 if desired. The operator is also given the option of looking at other old files, or scans, taking more data, or terminating the program. When the program has been terminated, the terminal will respond with a ".". At this time, the power bus can be shut off to power down all of the equipment.

3.4.2 Macro program

All data acquisition, DMA and A/D initialization and activation are done in Macro-11, the DEC machine language. A copy of this program is contained in Appendix D. A flow chart is given in Figure 23. An understanding

TABLE 9

CONVERSION FACTORS

Range	Gain Code			
	0	1	2	3
0 to 10	.244	.488	1.22	2.44
-10 to +10	.488	.976	2.44	4.88
0 to 5	1.221	1.221	1.22	1.22
- 5 to 5	2.442	2.442	2.44	2.44
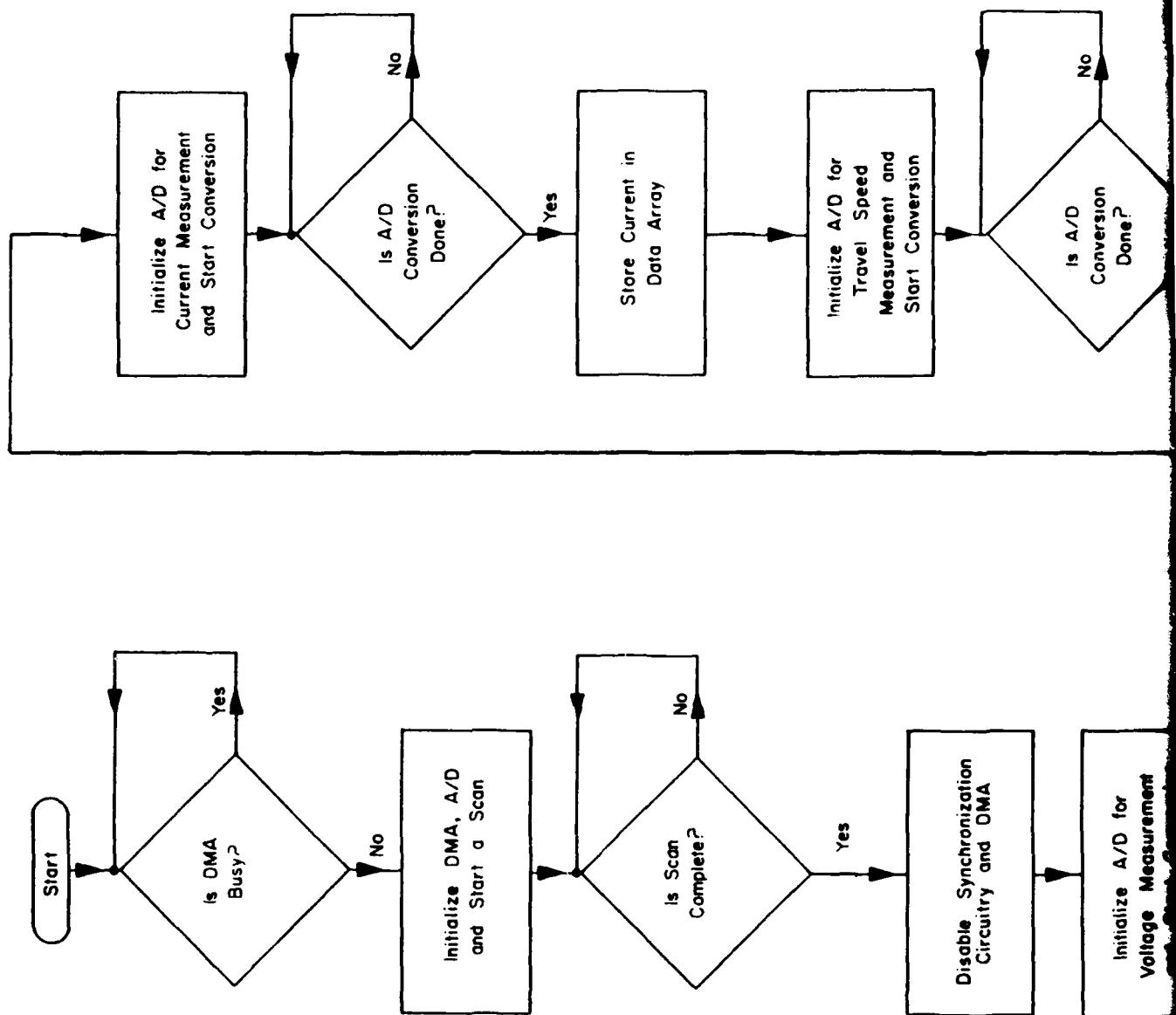
Figure 23. Flowchart of macro program.

53
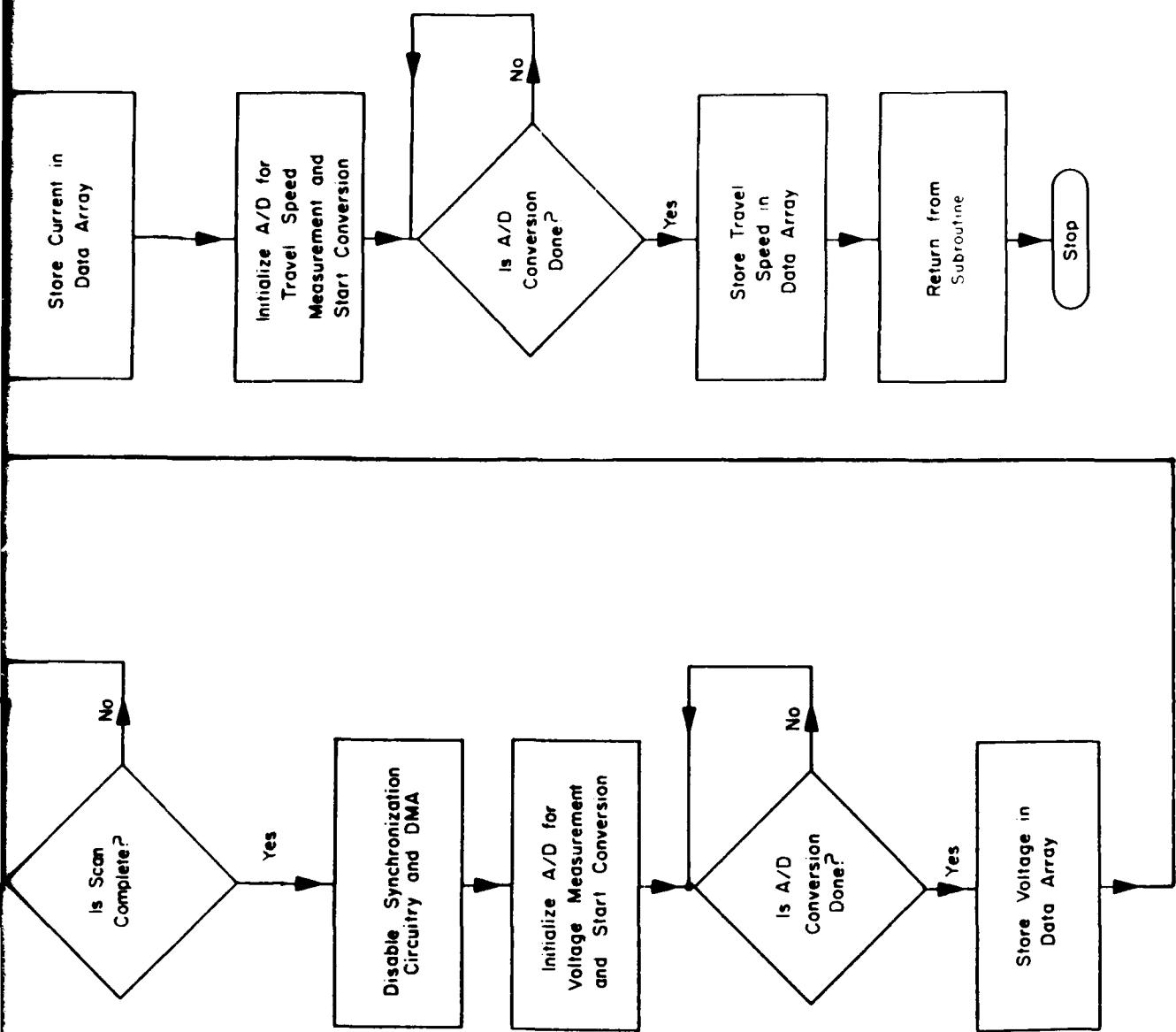
Flowchart of macro program.

of the operation of the ADAC A/D and DMA, the synchronization circuitry, and the Macro-11 is needed to truly understand this program. This information can be found in the appropriate section of this report with the exception of information on Macro-11 programming. Two reference sources for this information are the DEC RT-11 Operator Manual [8], vol. 3, "Macro-11 Language Reference" and Minicomputer Systems Organization, Programming, and Applications (PDP-11), by Richard H. Eckhouse, Jr., and L. Robert Morris.

Two features of the program that are not described in the usual Macro-11 documentation are .GLOBL, .TITLE, and .PSECT: RT-11 system macros. .GLOBL is a system macro subroutine that allows the argument of the statement to be accessed globally by other programs of the same or different languages. .TITLE is a means of specifying a title for the program as listed in the floppy directory. The .PSECT directive allows absolute control over the memory allocation of a program at link time, because any program attributes established through this directive are passed to the linker. The directive is formatted as follows: .PSECT name, arg1, and 2, ..., argn. Name represents the symbolic name of the program section. Arg represents one or more of the legal symbolic arguments defined for use with the .PSECT directive. The arguments are described in the following manner:

ARGUMENT	DEFAULT	DESCRIPTION
RO/RW	RW	RO = Read—Only Access RW = Read/Write Access defines which type of access is permitted to the program section.
I/D	I	Defines the program section as containing either instructions (I) or data (D).

ARGUMENT	DEFAULT	DESCRIPTION
GBL/LCL	LCL	Defines the scope of the program section, as subsequently interpreted at link time. If an object module contains a local program section, then the storage allocation for that module will occur within the segment in which the module resides. Many modules can reference this same program section. If an object module contains a global program section, the contributions .to this program section are collected across segment boundaries, and the allocation of memory for that section will go into the segment nearest the root in which the first contribution to this program section appeared.
ABS/REL	REL	Defines the relocatability attribute of the program section. ABS = Absolute (nonrelocatable). When the ABS argument is specified, the program section is regarded at link time as an absolute module, thus requiring no relocation. REL = Relocatable. When the REL argument is specified, the linker calculates a relocation bias and adds it to all references to locations within the program section.
CON/OVR	CON	Defines the allocation requirements of the program section. CON = Concatenated. All program section contributions are to be concatenated with other references to this same program section in order to determine the total memory allocation requirement for this program section. OVR = Overlaid. All program section contributions are to be overlaid. Thus, the total allocation requirement for the program section is equal to the largest allocation request made by any individual contribution to this program section.

For further information on this directive, see the RT-11 Operator Manuals, "RT-11 Advanced Programmer's Guide," Section 6.8.1, pp. 6-32; 6-36 [8].

The following is a step-by-step description of the Macro program itself.

1) .TITLE INIT.MAC

The .TITLE macro directive is used to place the title of the program

at the top of the program li'   :g. In this case, it is INIT.MAC.

2) .GLOBL DMAIT

The .GLOBL macro directive is used to allow the argument of the

directive to name a program section that can be collected across

segment boundaries in memory. In this case, DMAIT is made available

to the FORTRAN program AQSPEC.

3) DMAIT: TSTB @#172414

DMAIT: is a label used to name this line of code for external reference.

TSTB translates to TeST Byte. This command sets the condition codes

for the processor status word in the microcomputer. Since the test

is performed on the lower byte of the word 172414, the seventh bit

will determine the sign of the byte. The seventh bit is the sign

bit of a byte in two's complement arithmetic. Bit 7 of word 172414

is the busy bit on the DMA Control Status Register. If it is equal

to a 1, it is negative; if it is $\emptyset$, it is positive.

4) BPL DMAIT

BPL translates to Branch if PLus. If the BUSY bit is a one (bit

seven is a sign bit on a two's complement byte) or negative, go to the

argument of this command: DMAIT. If it is not a 1, continue to the

next instruction in the program.

5) MOV #176000, @#172410

The MOV command takes the first operand, 176000, and moves it into

the second operand, @#172410. The actual number 176000 (i.e., -1024

decimal) is moved into the word at location 172410 in the memory.

57

172410 is the Word Count Register (WCR) in the DMA. The WCR stops

DMA transfers when its content equals zero. After each DMA transfer,

the WCR is incremented by one. Thus, 2000 octal transfers or 1024

decimal transfers will be made before the WCR equals zero.

6) MOV_TOT,@#172412

The effect of this command is to place the memory address associated

with the label TOT (TOT is the first word location in a linear array

that is 1024 elements long) into the Memory Address Register (MAR)

in the DMA. The MAR is used to keep track of the current location

for the data storage. It is incremented after each data transfer.

7) MOV #1,@#172414

The effect of this command is to place a 1 in the least significant

bit of the word at location 172414. Location 172414 is the DMA

Control Status Register (CSR). The bit in question allows the DMA

to be enabled.

8) MOV #1,@#172416

Location 172416 is the Multiplex Comparison Register (MCR) in the

DMA. The MCR is used if conversions on each channel are to be done

sequentially from channel to channel. Since we wish to sample one,

a one is placed in the MCR to indicate that only one channel is to be

sampled.

9) MOV #32,@#177000

Location 177000 is the Control Status Register for the A/D. The octal

value of 32 configures the A/D for an external enable or trigger, unity

gain, and conversion on channel 0.

10) MOV #1,@#167772

This command will set the output channel 0 high (+5 V) on the parallel
I/O board. This enables the synchronization circuitry to begin
triggering of the A/D.

11) 1$: TSTB @#172414
       BPL 1$

Until 1024 conversions and data transfers have been completed, the
BUSY bit in the DMA CSR will be set equal to a 1. When it is set
equal to a $\emptyset$, the program will continue.

12) MOV #0,@#167772

This command sets the output channel 0 on the parallel I/O board
to ground so that the synchronization circuitry is disabled.

13) MOV #0,@#172414

This command will disable the DMA.

14) MOV #431,@#177000

The octal number 431 will force a conversion with unity gain on
channel 1 of the A/D. Channel 1 is the weld arc voltage.

15) LP1: TSTB @#177000
        BPL LP1

When bit 7 of the A/D CSR is set, the A/D has not finished a
conversion. When the A/D finishes, the program will continue.

16) MOV #TOT+16.,R1

The memory location TOT plus the decimal value of 16 will equal the
ninth word in the linear array following TOT. This word will be
used to store the value of the voltage. R1 is a general-purpose
register in the LSI-11/23 microprocessor that will be used to point
to locations in the array.

17) MOV @#177002,(R1)+

Location 177002 is the data buffer for the A/D. Since step 15 has

been completed, the data buffer will contain the converted value

for the voltage. (R1)+ has the effect of opening the contents of

the location of the address pointed to by the value in R1 for

deposit of the converted value for voltage. The + increments the

value of R1 by 2 after the completion of the instruction, thus forcing

R1 to point to the next word in the array TOT.

```
18)         MOV #1031,@#177000
      LP2:  TSTB @#177000
            BPL LP2
            MOV @#177002,(R1)+
```

The instructions above perform the same function as steps 14, 15,

and 17; however, they apply to channel 2 on the A/D which has the

weld arc current as an input.

```
19)   MOV #1431,@#177000
      BPL LP3
      MOV @#177002,(R1)
```

These instructions perform the same function as steps 14, 15, and 17;

however, they apply to channel 3 on the A/D which has the weld travel

speed as an input.

20) END1: RTS PC

RTS translates to ReTurn from Subroutine. PC is the Program Counter

and must be restored to its original value before the subroutine

was called so that the computer can start at the right location in

the calling program.

21) .PSECT TOT,RW,D,GBL,REL,OVR

A complete description of the macro directive PSECT is given just
prior to this section of text.

22) TOT: .BLKW 1024.

.BLKW translates into BLocK of Words. This macro directive has the
effect of creating an array of words which is as long as the number
following the directive. 1024. forces the number to be considered as
a decimal number as opposed to an octal one. Thus, the array is
1024 words long. TOT is a label that will be set equal to the
value of the memory location of the first word in the array.

23) .END DMAIT

This macro is used to define the absolute end of the program. Its
argument must reference the first executable statement of the program.

It should be noted that Macro-11 code, as in this case, is usually only
used when speed and efficiency are required.

4. OPERATING PROCEDURE

Before data acquisition can be accomplished, the following cables must be connected. The numbers circled refer to the corresponding numbers in the figures on pages 68-75 unless otherwise specified.

1) Be sure all power lines from devices on the rack are plugged into the power bus at the top of the rack. At this time, do not plug the power bus into an outlet.

2) All boards should be firmly secured in the back plane of the LSI-11 housing.

3) Six cables that must be in place at this time are: a ribbon cable from the RX02 floppy disk drive to the RXV21 board ① (Figure 24); a ribbon jumper cable from the A/D to the DMA ② (Figure 25); a shielded ribbon cable from the A/D to the spectrograph control box ③ (Figures 24, 25, and 26); a cable running from channel 3 of the DLV-J serial interface board to the Decwriter LA-120 ④ (Figures 25 and 27); a ribbon cable running from the MDB MISI-DRV11-C parallel interface board to the spectrograph control box ⑤ (Figures 24, 25, and 26); and a ribbon cable running from the spectrograph control box to the spectrograph ⑥ (Figures 24 and 26). With the exception of the last cable mentioned, none of these cables should be removed while the computer is powered up.
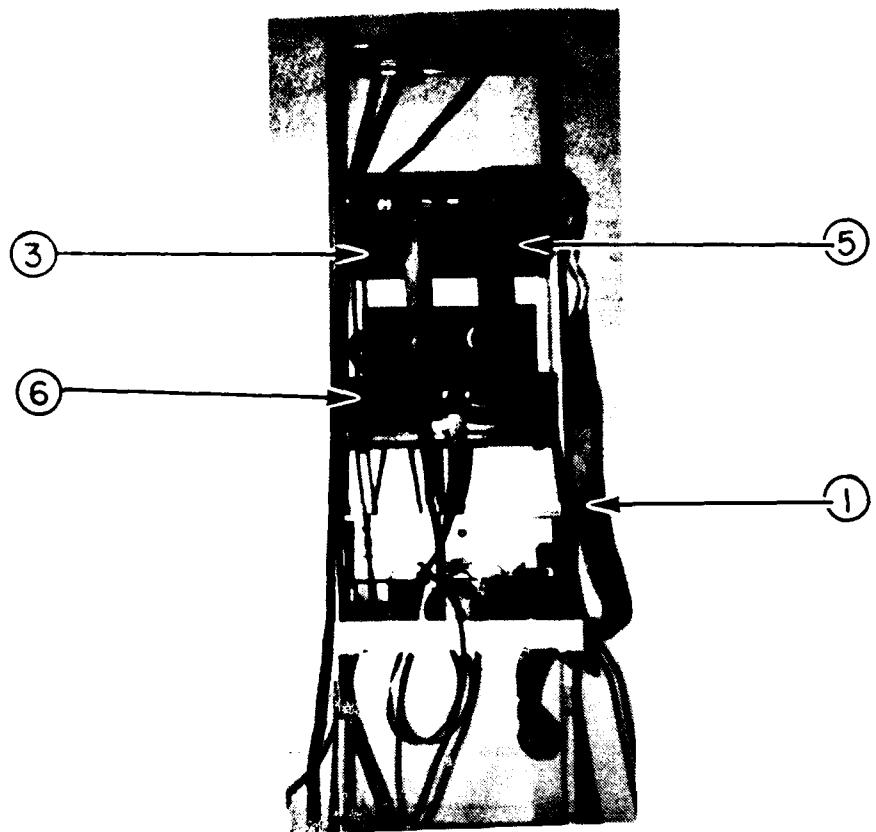
Figure 24. Back view of WQM.
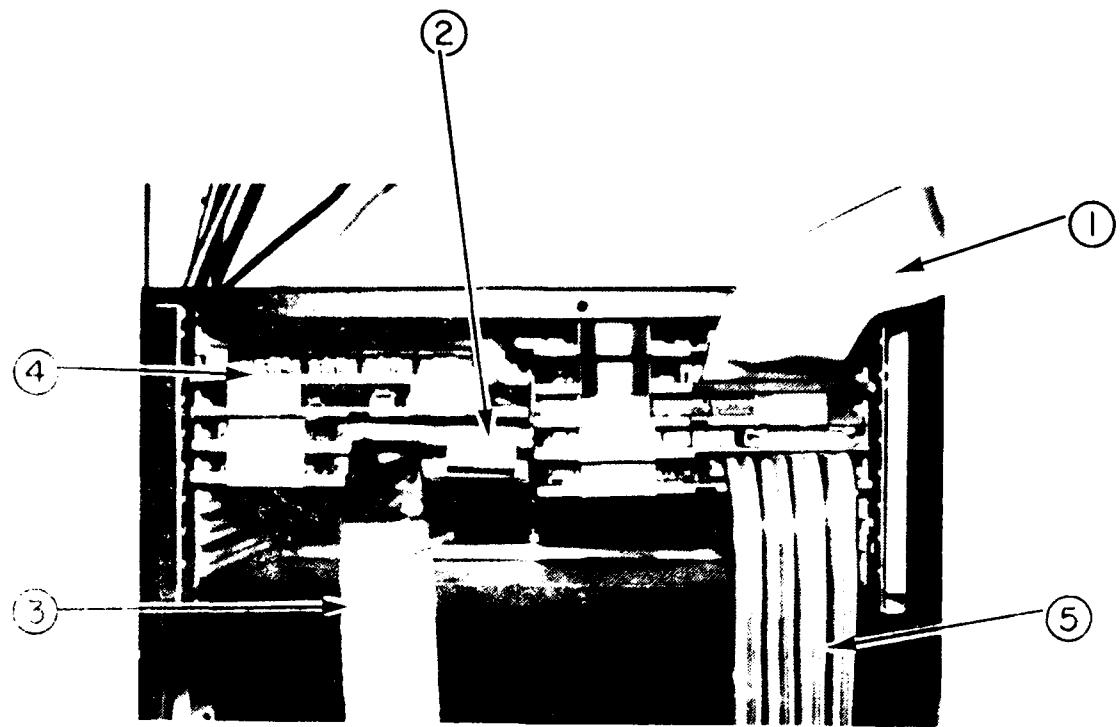
Figure 25. Backplane of DEC minicomputer.
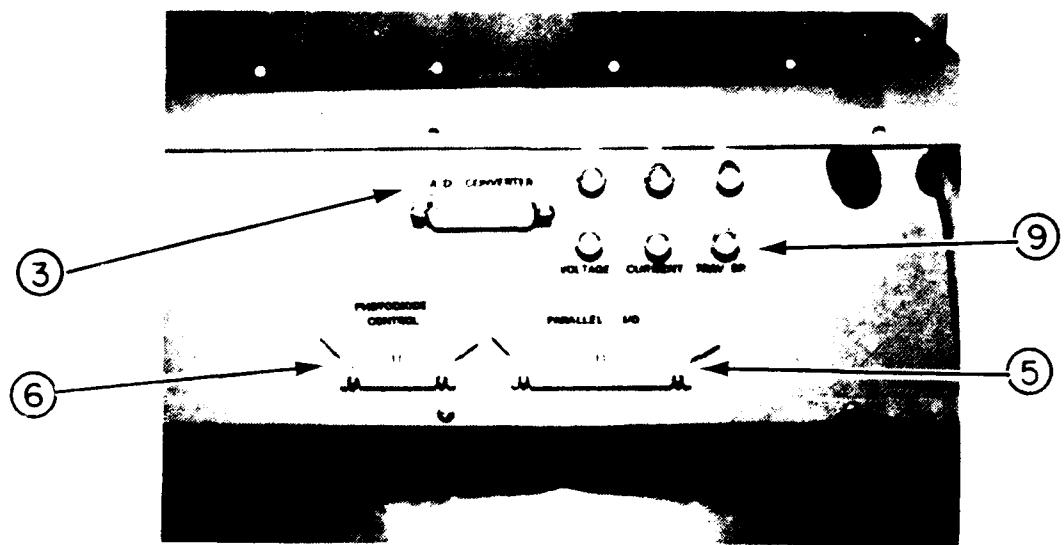
Figure 26. Back of spectrograph control box.

Figure 27. Decwriter LA-120.

If a video display of the spectrum is desired, connect one end of an BNC cable to the START OUT (7) (Figure 28) on the spectrograph control box and the other to the oscilloscope trigger. Connect another BNC to the VIDEO OUT (8) (Figure 28) on the spectrograph control box and an inverted channel on the same scope.

5)   If voltage, current, and travel speed are desired, connect the appropriate BNC's to the back of the spectrograph control box (9) (Figure 26).   The range of these inputs must be restricted to 0-10 V. If these ports are not to be used, they must be shorted for the proper operation of the system.

6)   Plug the power cord from the power bus into a 110 V outlet and turn the bus on.   The system is now ready for initialization.

After the steps above have been completed, the following procedure can be used to initialize the software for data acquisition.

1)   Turn the computer power switch (10) (Figure 29) and the spectrograph control box power switch (11) (Figure 28) on.

2)   Take the RT-11 system software and data acquisition floppy disk and slide it into slot 0 (12) (Figure 30) in the RX02 disk drive.   Close the door over the slot.   (The slot cover is opened by depressing a button under the handle on the slot cover.)

3)   Slide a formatted and initialized data floppy disk (see Appendix B) into slot 1 (13) (Figure 30) in the RX02 disk drive and close the door.
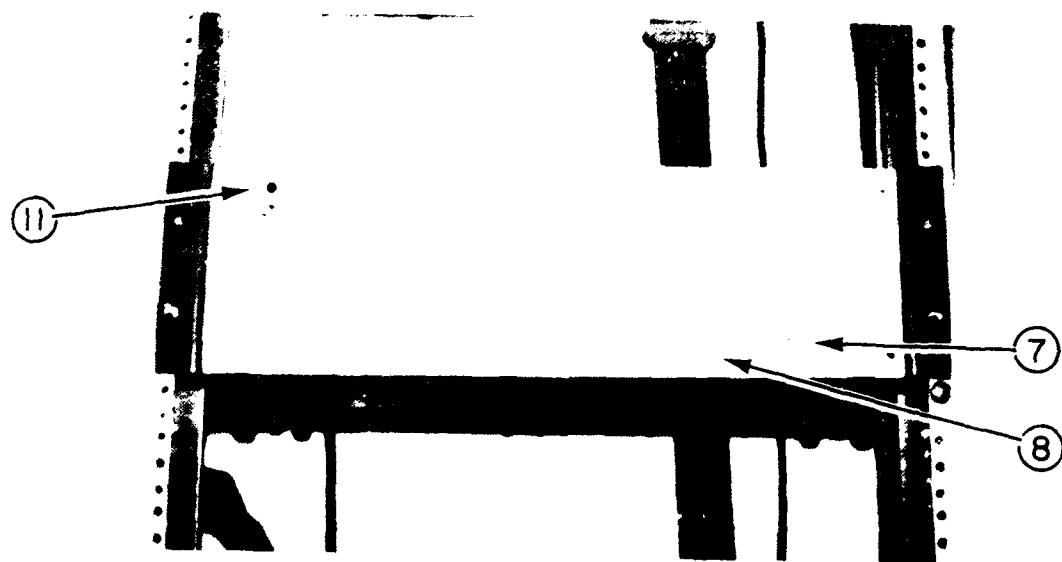
Figure 28. Front of spectrograph control box.
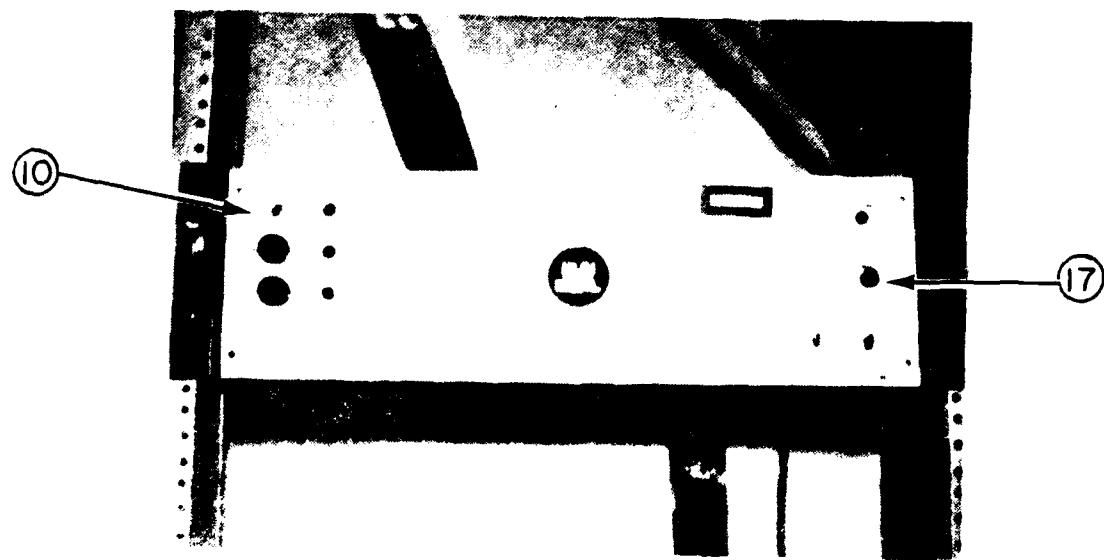
Figure 29. Front of PDP minicomputer.
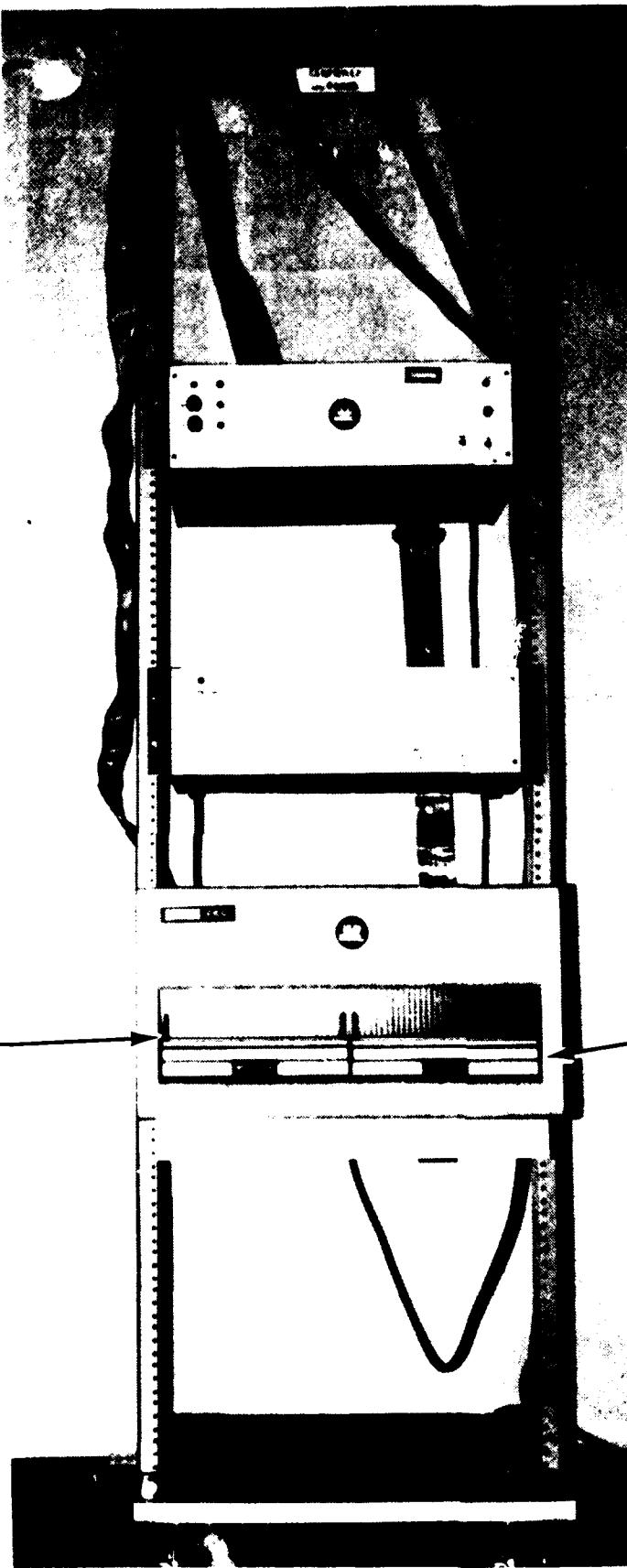
Figure 30. Front of WQM.

4) Turn the LA120 power switch ⑭ (Figure 27) on.

5) Check to see that the LA120 indicator light is "ON LINE" rather than "LOCAL" ⑮ (Figure 31) [10]. If it is on "LOCAL," press the ON LINE/LOCAL button ⑯ (Figure 31) [10].

6) Press the system initialization button ⑰ (Figure 29) and wait for this response on the LA120:

> UI PHYSICS RT-11FB (S)V03B-02
>
> ?KMON-F-File not found

The following information will detail the computer interface with the WQM operator and the possible responses. A ●, will precede anything that the computer will type at the terminal. The response by the user is underlined. After the possible user response, there will be a description of the computer action taken and the step number of the next question.

7) ● .	;This is the computer prompt.
DATE 7-JUL-81	;The date shown is representative of the way the date is entered.
8) ● .	
TIME 13:48:00	;The value for the time is arbitrary but illustrates the way time is entered into the system.

Note: The date and time must be reset for every system initialization. Also, to erase characters entered, type the delete button until the error is reached. Then, retype the information to correct the mistake.
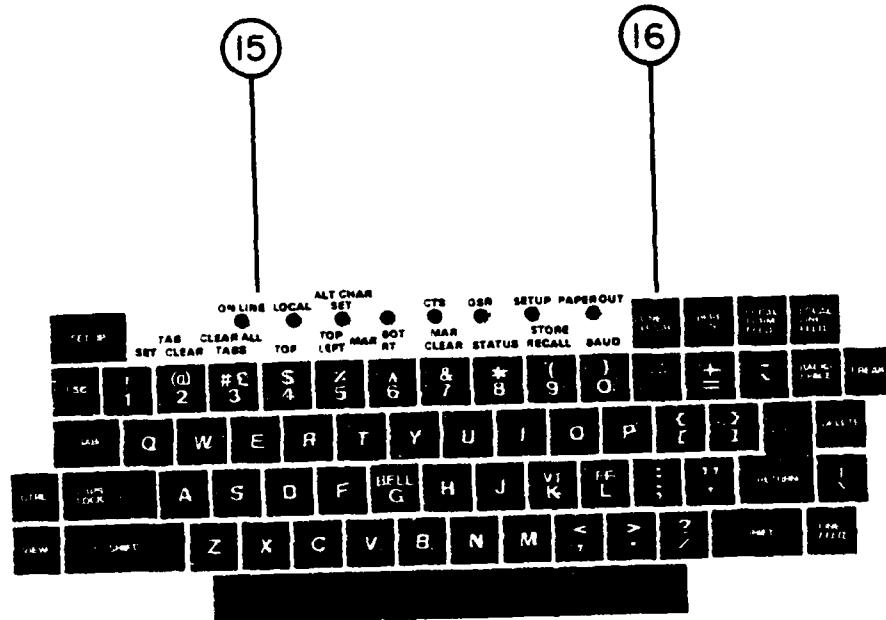
Figure 31.   Keyboard for Decwriter LA-120 [10].

9) ●   .

      <u>RUN AQSPEC</u>   ;This will start the data
                                                collection program.

10) ● DO YOU WISH TO LOOK AT AN OLD FILE?
    ● TYPE Y FOR YES, N FOR NO.

      <u>Y</u>   ;This answer will take the
                                                operator to step 17 to
                                                specify the file that is to
                                                be seen.

      <u>N</u>   ;Go to step 11.

11) ● DO YOU WISH TO TAKE A SINGLE OR AVERAGE SCAN?
    ● TYPE S OR A.

      <u>S</u>   ;This will enable the
                                                operator to take a cali-
                                              bration scan with the
                                              spectrometer. It will
                                              automatically print the
                                              scan at the LA 120. An
                                              example of a calibration
                                              scan can be found in
                                              Appendix G. Go to step 14.

      <u>A</u>   ;Go to step 12.

12) ● HOW MANY SPECTRA ARE TO BE AVERAGED?
    ● TYPE A NUMBER BETWEEN 1 AND 9.

      <u>5</u>   ;The number 5 was chosen
                                                arbitrarily but it is
                                              representative of the way
                                              the operator would type in
                                              the number of scans the
                                              operator would have
                                              averaged for data storage.
                                              Go to step 13.

13) ● HOW MANY SCANS ARE TO BE TAKEN?
    ● TYPE UP TO A THREE DIGIT NUMBER.

      <u>50</u>   ;The number 50 was chosen
                                                arbitrarily but it represents
                                              the way an operator would
                                              enter the number of averaged
                                              scans that are to be stored.
                                              Go to step 14.

14) ● ENTER A SIX CHARACTER CODE WORD HERE.

     <u>TEST00</u>   ;This word can be any
combination of six or fewer
alphanumeric characters.
It will be used on the
floppy disk directory to
name the file created. All
references to this data
file must be done with the
file name in the future.
Go to step 15.

15) ● AT THIS TIME THE SYSTEM IS READY.
   ● TYPE R TO START A RUN OR A TO ABORT.

     <u>A</u>   ;This command will terminate
the acquisition of data as
previously specified. No
file will be created and no
data will be taken. Go to
step 12.

     <u>R</u>   ;This command will begin the
data acquisition and
storage. When the computer
next responds with a
question, the data will have
been taken and stored under
the code word specified
earlier. Go to step 16.

16) ● DO YOU WISH TO SEE THE RESULTS?

     <u>N</u>   ;Go to step 11.

     <u>Y</u>   ;This command will allow the
operator to view the data
on the LA 120. Go to step
17.

17) ● WHAT FILE CODE DO YOU WISH TO ACCESS?
   ● TYPE A SIX CHARACTER CODE WORD.

     <u>TEST00</u>   ;The code word shown is just
for purposes of illustration.
It can be any six or fewer
alphanumeric characters
corresponding to an existing
file on the floppy disk in
slot 1 of the floppy disk
drive. Go to step 18.

18) ● TYPE A THREE DIGIT SCAN NUMBER.

     <u>28</u>   ;The number shown was arbitrarily selected. It can be any number that corresponds to a set of averaged spectral scans stored in the file specified in step 8. The number must correspond to a number less than or equal to the total number of average scans taken for that file. The scan specified will be printed out automatically. An example of the output is shown in Appendix F. Go to step 19.

19) ● DO YOU WISH TO SEE ANOTHER SCAN?
    ● TYPE Y FOR YES, N FOR NO.

     <u>Y</u>   ;This question asks the operator if he would like to see another scan number in the same file that was opened in step 8. With this command, *the operator* will proceed to step 18.

     <u>N</u>   ;Go to step 20.

20) ● DO YOU WISH TO SEE ANOTHER FILE?
    ● TYPE Y FOR YES, N FOR NO.

     <u>Y</u>   ;This question will allow the user to access any file that exists on the floppy disk in slot 1 of the floppy disk drive. With this answer the operator will proceed to step 17.

     <u>N</u>   ;Go to step 21.

21) ● DO YOU WISH TO TAKE ANOTHER SCAN?
    ● TYPE Y FOR YES, N FOR NO.

     <u>Y</u>   ;This question asks the operator if he wishes to continue taking data. With this answer the operator proceeds to step 11.

73

<u>N</u>   ;This answer will terminate
                                         the program. Wait for the
                                         computer to respond with
                                         its prompt before rerunning
                                         the program or starting the
                                         power off procedure.

22) To stop operation, turn off the power switch on the LA 120
     and the power bus at the top of the rack.

5. EXPERIMENTAL RESULTS

To illustrate the capabilities of the system, results of two experiments are described in this section. Both experiments were bead on plate tests using the shielded metal arc welding process with argon shielding gas, carbon steel base metal, and E70S-3 electrodes (see Figure 32).

In the first experiment, the argon shielding gas was interrupted during the welding process and the resultant changes in the arc spectrum, voltage, and current observed. Complete or partial loss of shielding gas can cause flaws such as porosity and slag in the weld joint. In the past, attempts have been made by other workers to monitor shielding gas flow using pressure transducers; this approach has not been very successful. The experimental procedure was as follows:

With the shielding gas on, the arc was stabilized by adjusting the current to 300 A. Data collection was then initiated by the computer and continued for 50 seconds. Samples of the arc spectrum, voltage, and current were averaged for one-half second and then stored on a disk. Because the access time for the disk is approximately one-half second, data were collected at one-second intervals. Approximately 10 seconds after data collection was initiated, the argon shielding gas was turned off for 10 seconds. Shielding gas was turned on at 20 seconds, off again at approximately 30 seconds, then on at 40 seconds.

Figure 33 is a plot of the arc voltage and current versus time. The times during which the shielding gas was off are clearly evident. When the shielding gas is turned off, the arc current decreases from 300 A to approximately 250 A, and the arc voltage increases from 30 V to approximately

Figure 32. Weld spot and fiber.
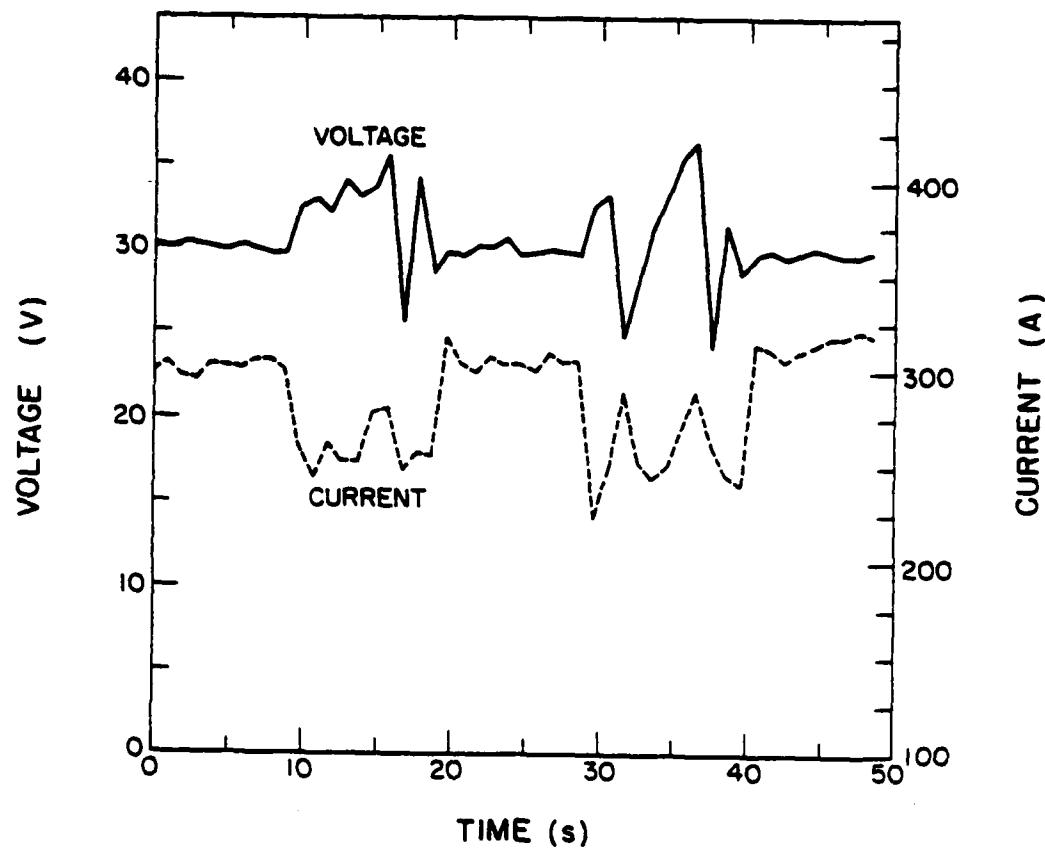
Figure 33. Variation of the arc voltage and current versus time.
The argon shielding gas was interrupted twice during
this experiment for approximately ten seconds each time.
The shielding gas was turned off at approximately
9 seconds and again at approximately 29 seconds.

77

34 V. Both the voltage and current fluctuate considerably when the shielding gas is off. With the removal of the shielding gas, the arc length decreases and the mode of metal transfer changes from spray to globular. The large globules of weld metal cause some shorting of the arc which in turn causes instability of the current and voltage. Notice that the voltage and current are anticorrelated. The voltage increases when the current decreases and vice versa. The primary parameter WQM, which is presently undergoing field tests at Chrysler and Allis-Chalmers, monitors only arc current and voltage.

Samples of the arc spectrum obtained simultaneously with the current and voltage data are plotted in Figure 34. Figure 34a is a sample of the arc spectrum taken at 28.71 seconds into the experiment. This represents an arc spectrum under normal welding conditions. In Figure 34b the arc spectrum at 29.70 seconds into the experiment is plotted. This represents the spectrum obtained for the flaw inducing condition of loss of shielding gas.

The wavelength range from 400 to 1000 nm corresponds to the spectral region from the near ultraviolet to the near infrared and includes the visible region of the spectrum. The spectral lines with wavelengths longer than 700 nm are due to excitation of the argon shielding gas by the arc. When the shielding gas is removed, these spectral lines disappear. Repeated tests show an unambiguous correlation between the loss of the long wavelength lines and the loss of the argon shielding gas.

To further illustrate this point, the total spectral energy between 700 to 1000 nm is plotted versus time in Figure 35. When the shielding gas is on, the relative energy in this spectral segment is approximately 0.3. When the shielding gas is removed, the relative energy drops to approximately 0.1.
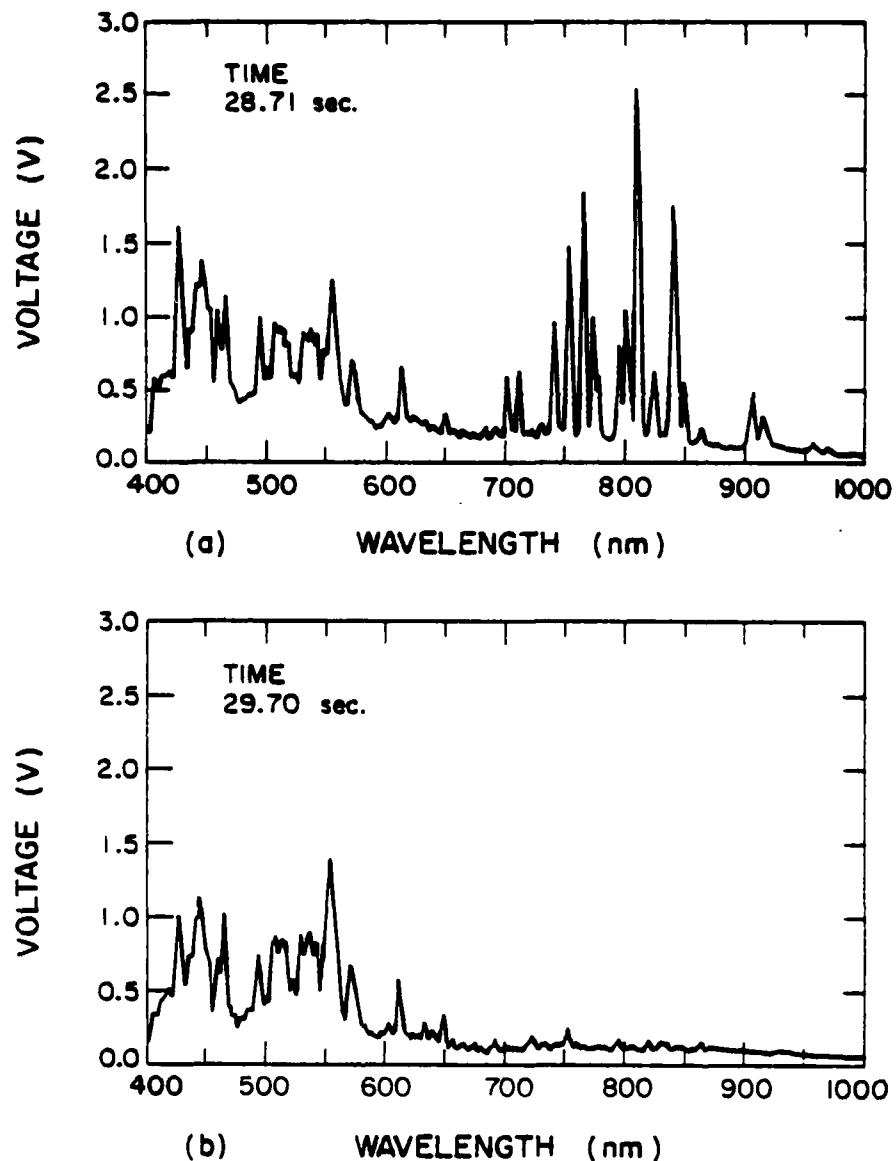
Figure 34. Typical examples of the arc emission spectra. Figure 34a is a spectrum obtained at 28.71 seconds into the experiment and corresponds to normal welding conditions where the argon shielding gas is on. Figure 34b is a spectrum obtained at 29.7 seconds into the experiment and corresponds to abnormal welding conditions when the shielding gas is off.
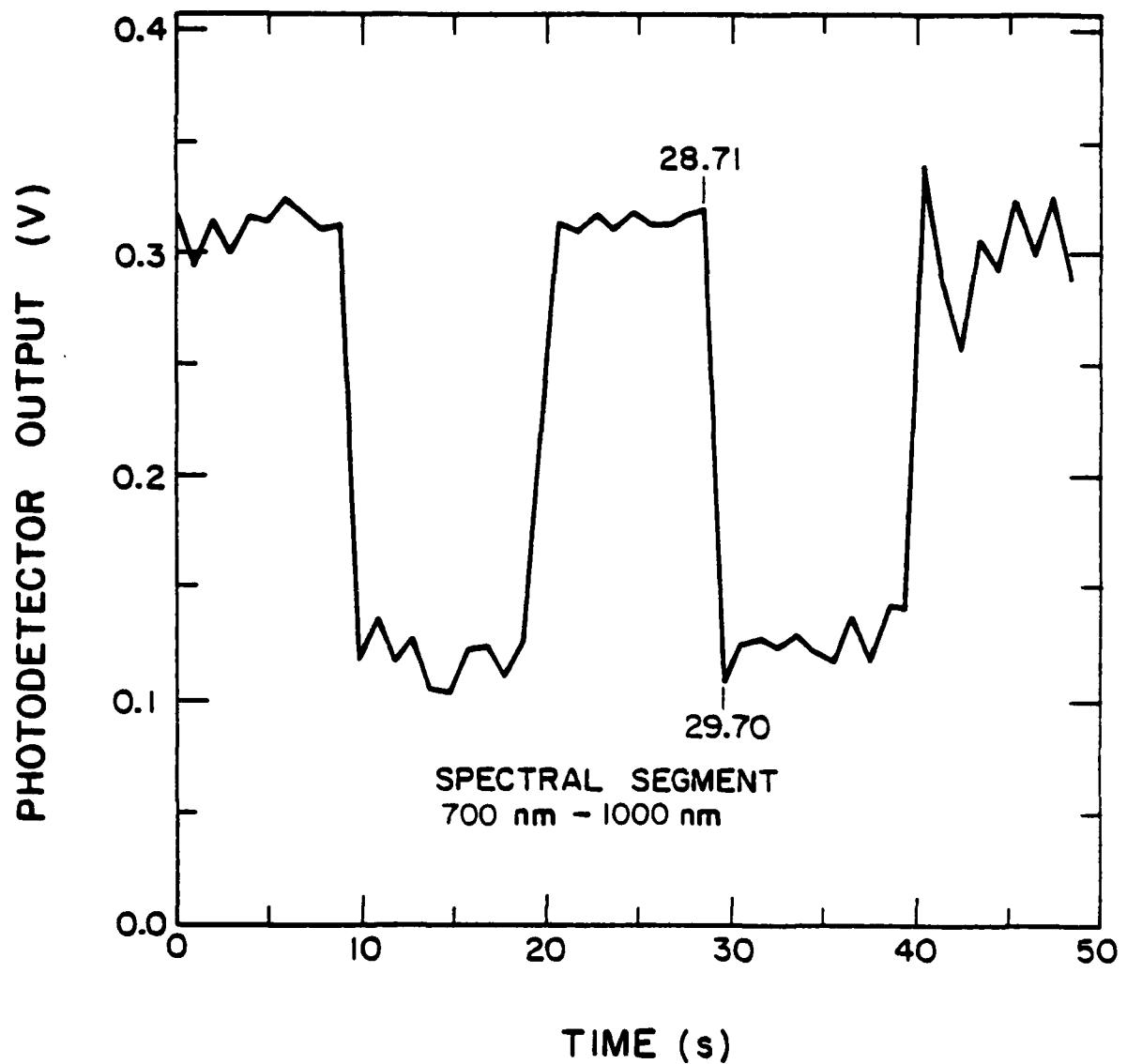
Figure 35.   Total energy in the spectral segment from 700 to 1000 nanometers.

The times annotated on Figure 35 correspond to the times at which the spectra

in Figure 34 were obtained (28.71 seconds and 29.70 seconds). The data

plotted in Figure 35 show that a complete loss of the shielding gas occurs in

less than one second. Although the time resolution of our system was one

second for this experiment, it can be increased to less than one-tenth of

a second, if necessary. Notice that all of the spectral energy was not

lost when the shielding gas was off. The residual energy in the 700 to

1000 nm wavelength range is due to black body radiation from the weld arc.

It may be possible to determine the temperature of the arc by fitting the

background spectral energy to the standard black body curve.

The total energy in the wavelength region between 400 and 700 nm is

plotted in Figure 36. Although the energy does decrease in this region when

the shielding gas is removed, the decrease is not as abrupt nor as significant

as that plotted in Figure 35. We believe the gradual decrease in energy is due

to the increase in smoke production when the shielding gas is interrupted.

The shorter wavelengths are attenuated by the smoke much more than the longer

wavelengths. Consequently, it is smoke that is attenuating the shorter wave-

lengths rather than loss of argon emissions in this spectral region. When

the shielding gas is turned on, the energy does not abruptly increase. It

takes awhile for the smoke to be cleared from the welding area. Notice

also that when the shielding gas is off, the energy fluctuates considerably

more than the energy in the 700 to 1000 nm region. The total energy

from 400 to 1000 nm versus time is plotted in Figure 37. This plot shows

the combined effect of loss of shielding gas on the near UV, visible,

and near IR regions of the arc spectrum.
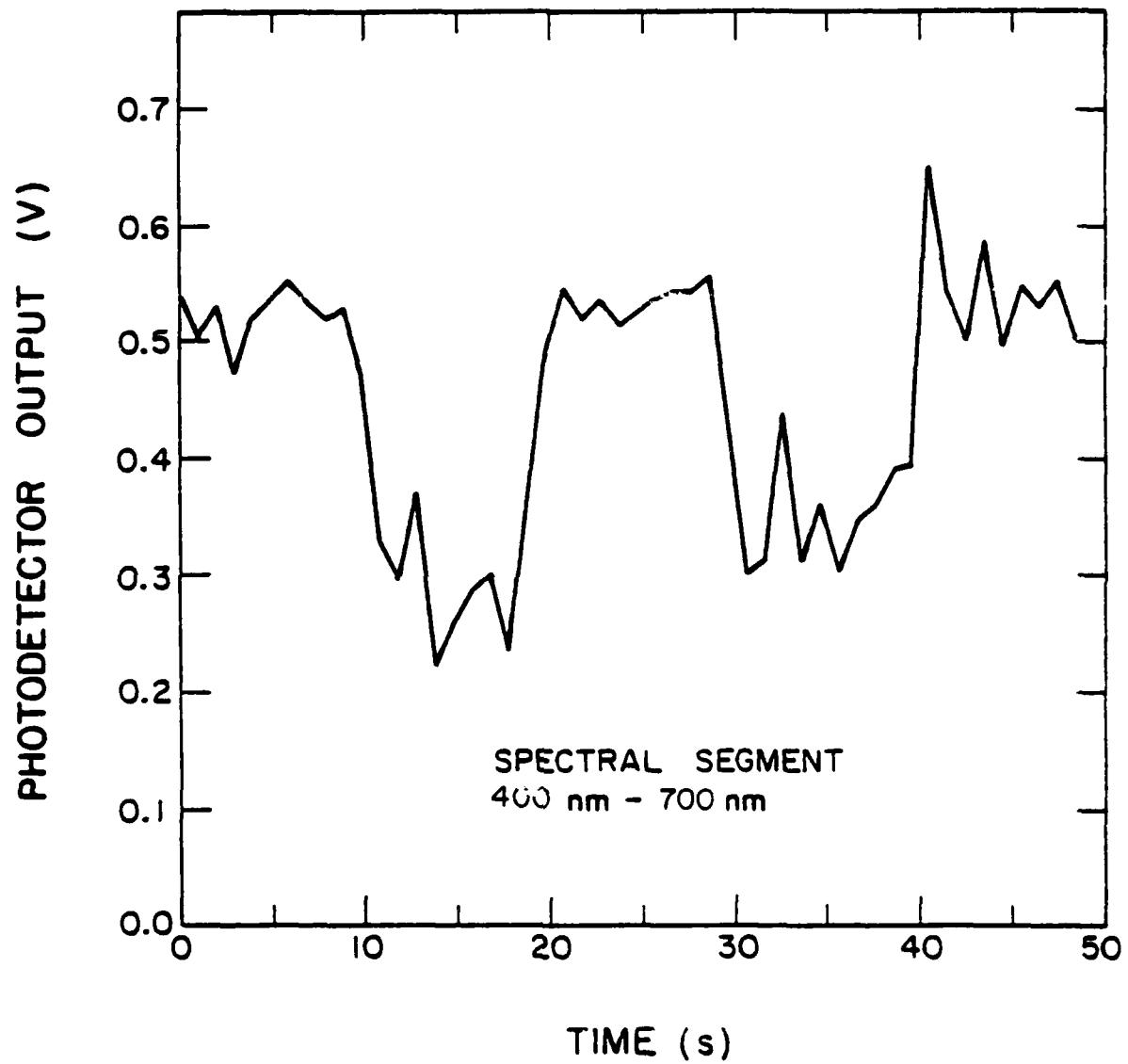
Figure 36. Total energy in the spectral segment from 400-700 nanometers.
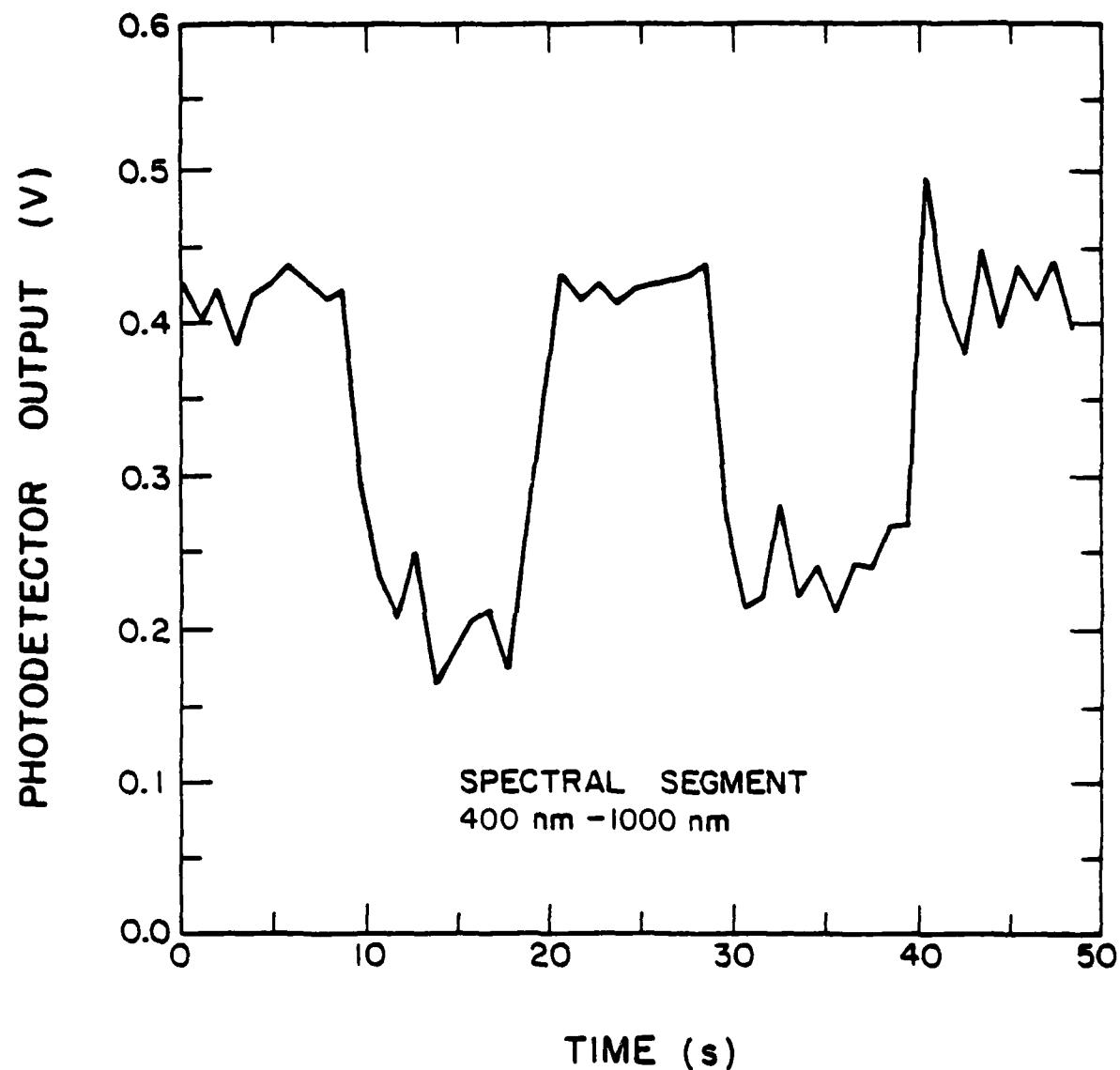
Figure 37.   Total energy in the spectral segment from 400 to 1000 nanometers.

Figure 38 is a plot of the energy in the argon line from 14 to 816 nm. The energy in this line changes by almost a factor of six when the shielding gas is removed. Obviously, a very simple shielding gas monitor could be constructed by using a narrow-band filter and photodetector to measure the spectral energy in the 814 to 816 nm wavelength region.

The physical results of loss of shielding gas are easily seen in macro etched cross sections of the welds made in this experiment. Figure 39a is the normal weld (shielded), with deep weld metal penetration, a fairly small heat affected zone, and an absence of visible slag inclusions or porosity defects. In Figure 39b the weld made without shielding gas is shown. The weld contains gross porosity, a slag inclusion, and a large heat affected zone. The shape of the weld bead is also flatter and more irregular than that of the sound weld.

The second experiment was designed to determine the correlation between heat input and the arc spectrum. Heat input is defined as the arc current times the arc voltage divided by the travel speed, and is usually given in units of kilojoules per inch. In this experiment the heat input was varied by varying the arc current. Figure 40 is a plot of the current and voltage as a function of time. The current was varied from approximately 200 to 360 amperes. Since the travel speed was constant at ten inches per minute, this corresponds to a variation in the heat input from approximately 36 to 55 kilojoules per inch.

Figure 42 is a plot of the total spectral energy from 400 to 1000 nm as a function of heat input. Figures 42 and 43 are similar plots for the energy in the 400 to 700 nm region and 700 to 1000 nm region, respectively. In all
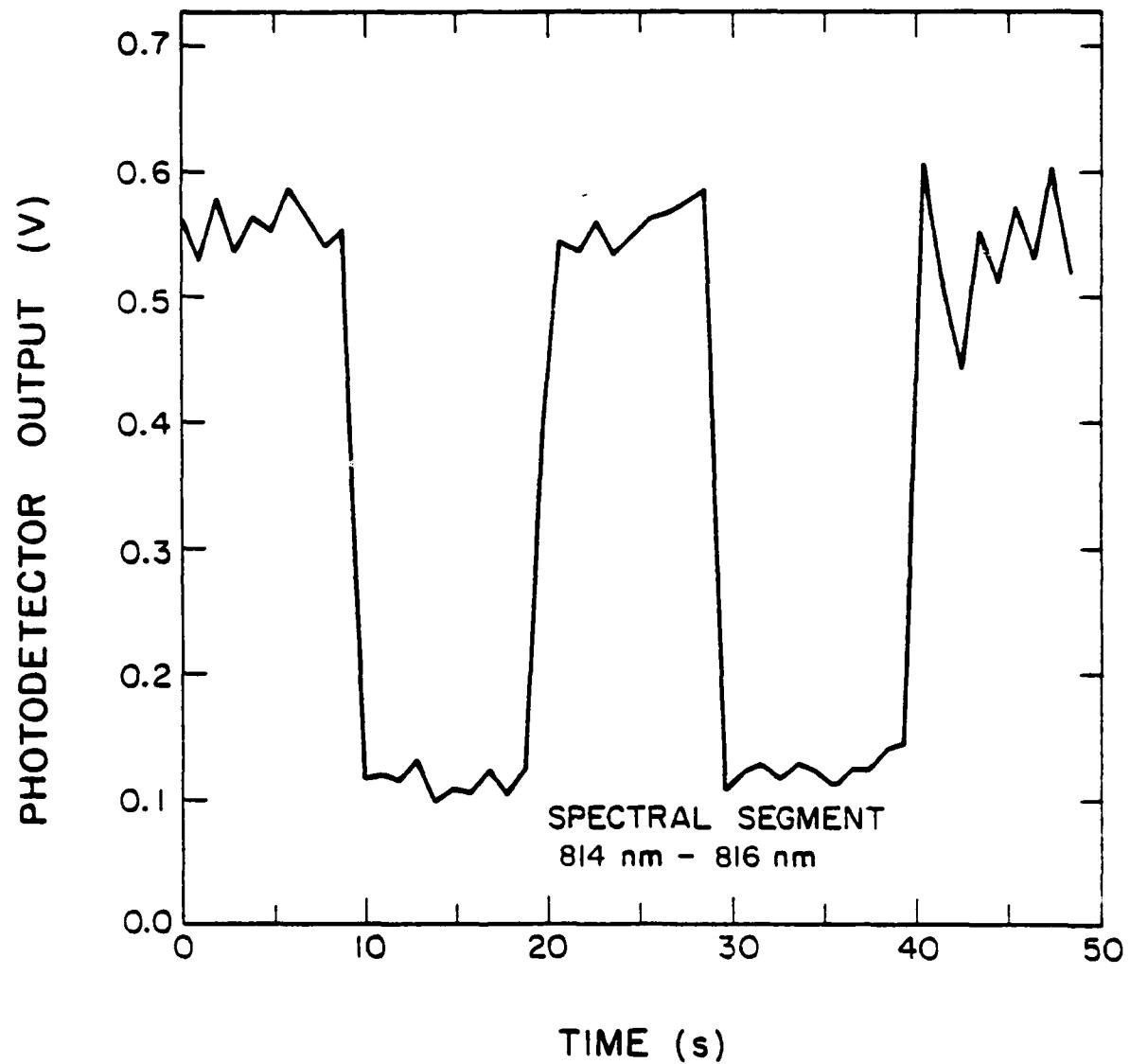
Figure 38. Total energy in the spectral segment from 814 to 816 nanometers.

85
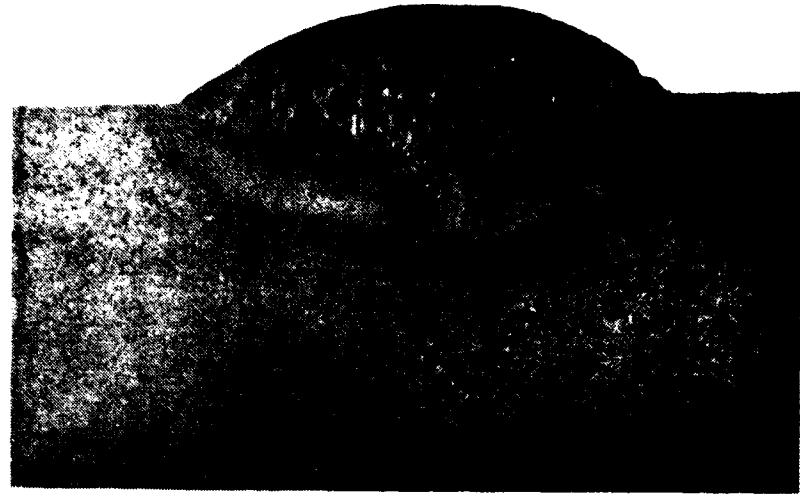
Figure 39. Macro etched across sections of welded joint. Figure 39a is the normal argon shielded weld while Figure 39b is the weld made without shielding gas.
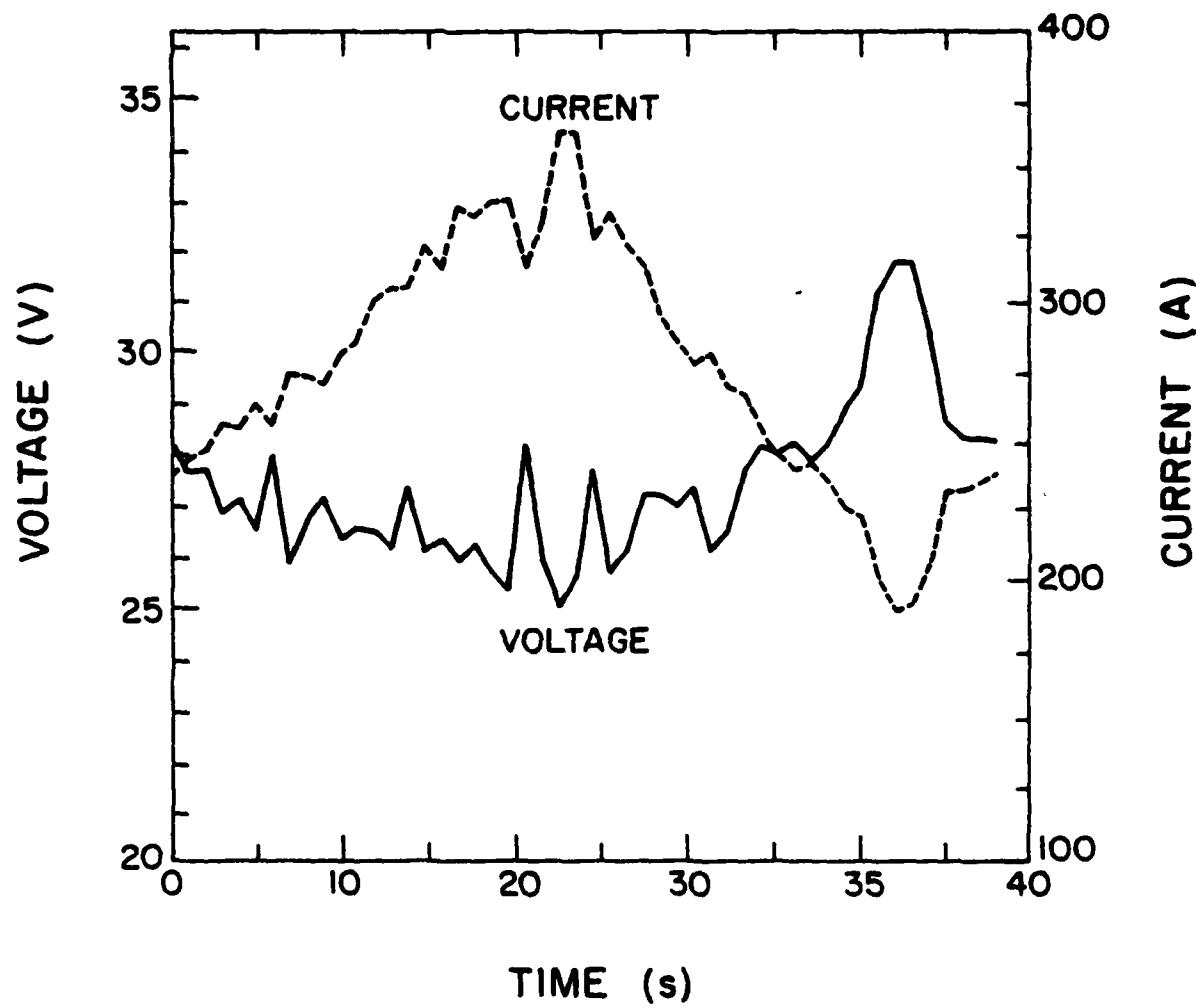
Figure 40.   Variation of the arc voltage and current versus time.   The arc
current was varied between approximately 200 and 360 A.
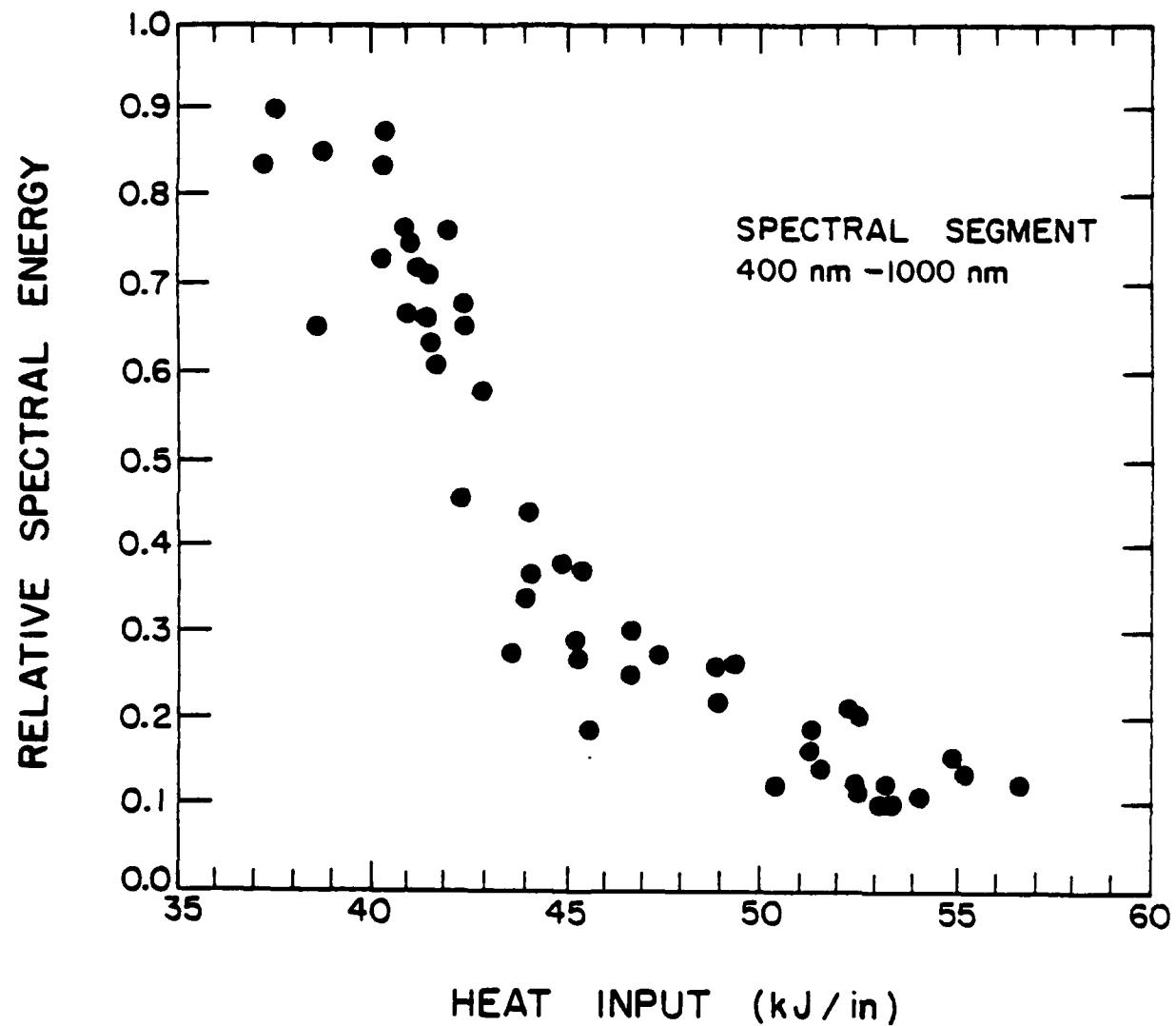
Figure 41. Variation of the total energy in the spectral segment from 400 to 1000 nm versus heat input.
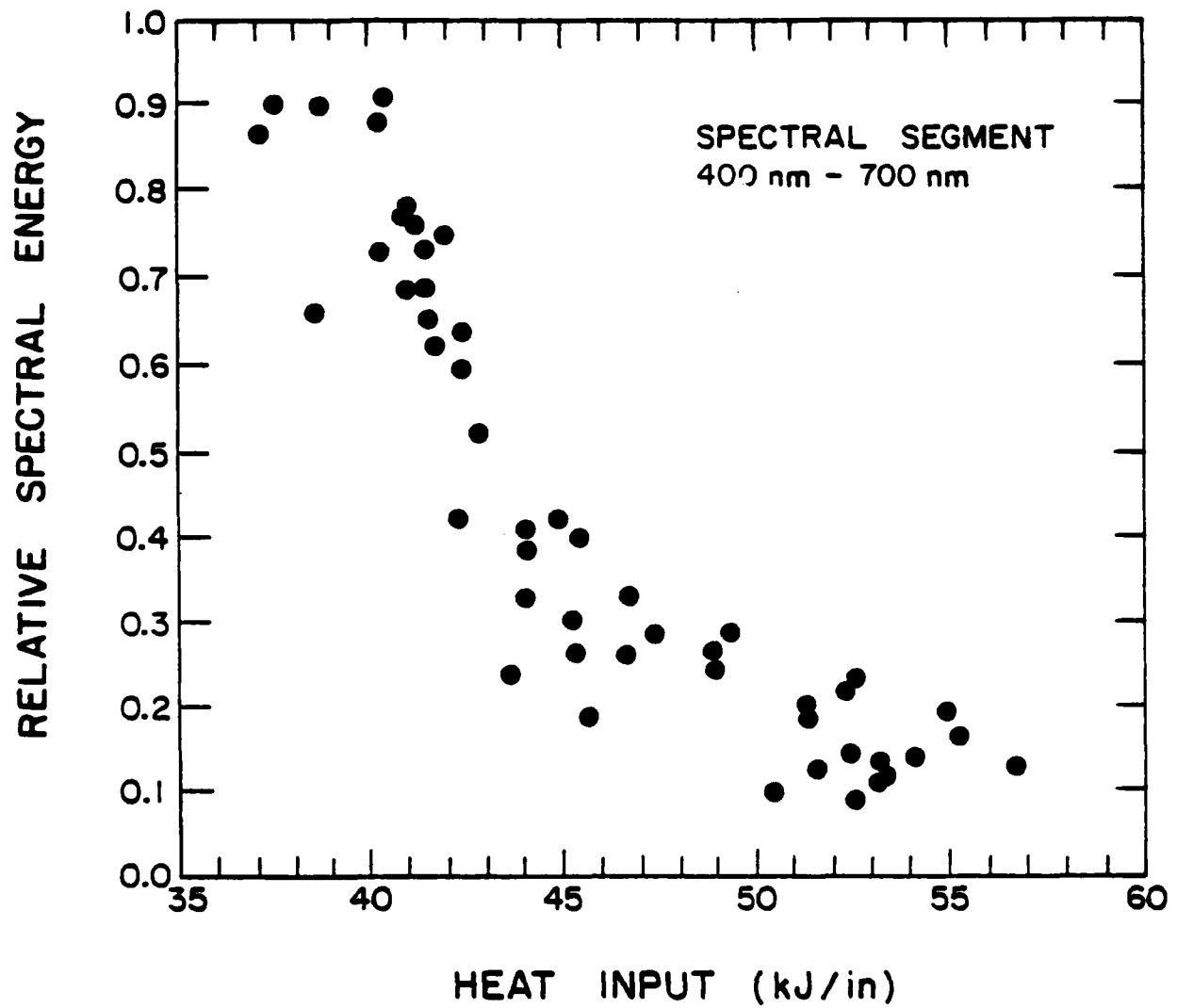
Figure 42.   Variation of the total energy in the spectral segment from
400 to 700 nm versus heat input.
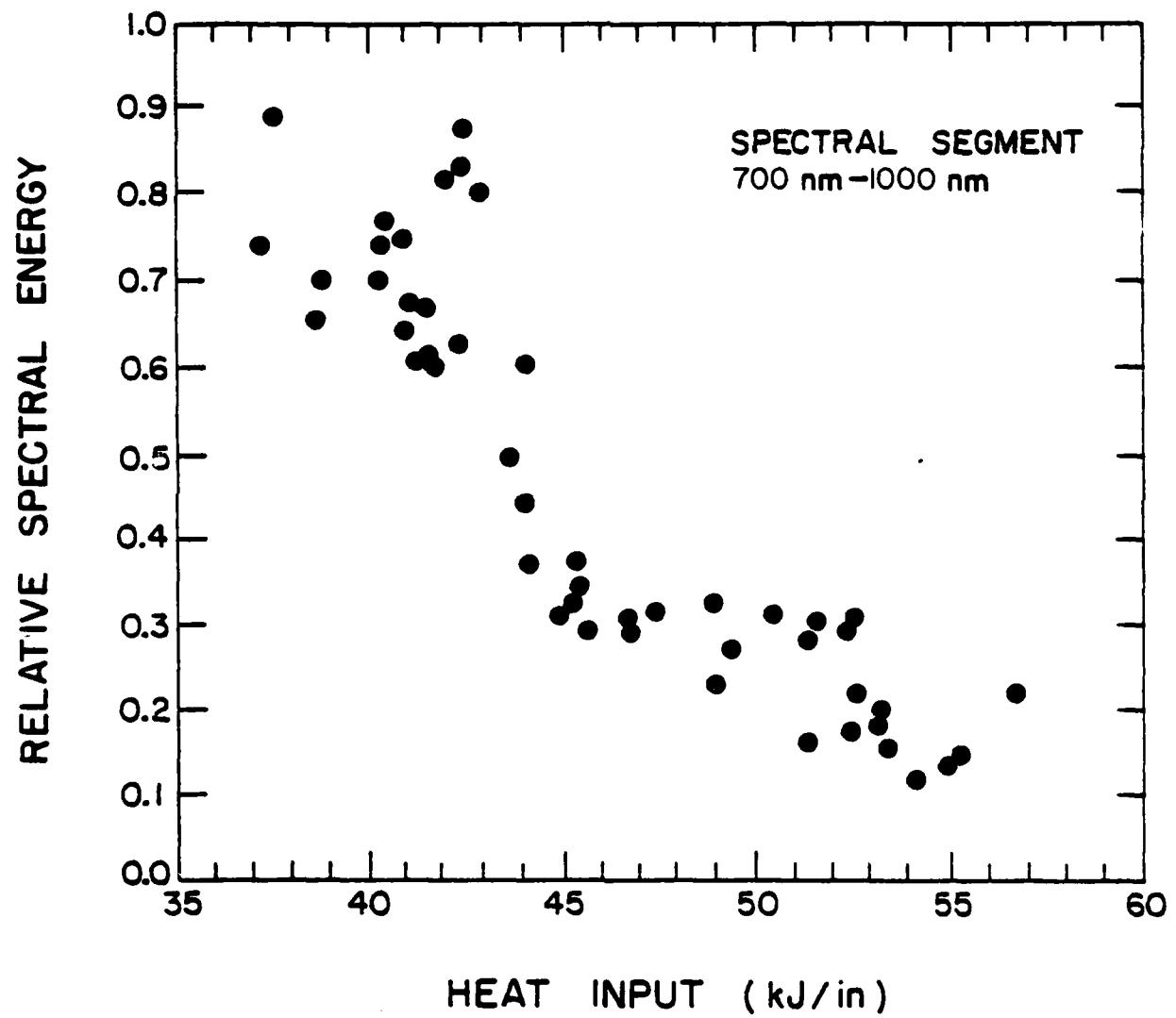
Figure 43. Variation of the total energy in the spectral segment from 700 to 1000 nm versus heat input.

three cases the general trend is for the spectral energy to decrease as the heat input increases. However, the decrease seems to be more pronounced and more systematic for the wavelength region between 400 to 700 nanometers. Because different regions of the spectrum behave differently as the heat input is changed, it may be possible to compute the heat input directly from the spectral data.

Both of the experiments described have been repeated several times at the CERL Welding Laboratory over a six-month period. Excluding hardware anomalies, the same results were obtained.

The real-time weld arc spectrum detection and analysis capabilities of this prototype optoelectronic system are demonstrated by the data presented. The confidence level of the system was established by reproducibility of results during the six-month testing period. An area for future development is resolution. Resolution improvements may prove to give additional weld quality information. In particular, hydrogen and sulfur contaminants may be detectable. Another area of development is the development of heat input/arc spectra correlation. This may be accomplished with a broader data base.

6. CONCLUSIONS

This report has described the software and hardware designs of the electro-optic Weld Quality Monitor. The system was developed to study the spectral and electrical characteristics of the weld arc. Included was a representative sample of data that was collected with the system. It is clear from observing changes in the weld arc spectrum that changes in arc voltage, current, and shielding gas flow are easily discernible in argon gas shielded welds. Additional experiments using different welding techniques are needed to establish the applicability of this system. Currently, weld parameter standards are either nonexistent or crude at best. It is hoped that, with the continued use and refinement of this system, standards will be established that provide improved weld integrity.

APPENDIX A

SPECIFICATIONS AND SCHEMATICS ON RETICON DIODE
ARRAY AND SCANNING ELECTRONICS

ALIGNMENT PROCEDURE FOR THE RC-100B MOTHERBOARD WITH RC-104, 105, OR 106 AND "G" SERIES ARRAY

1) Jumper Connections. Split pads are provided to program the RC-100B board for the desired configuration. Refer to p __ (Drawing Number 011-0238) for correct configuration.

2) Monitor . .. Adjust R2 for the desired frequency, 1 MHz maximum. Adjust R11 for a 700 ns negative going pulse width.

3) Monitor P2-b. Set the desired start pulse interval, using rocker switches S1, S2, and S3.

4) Monitor TP2 and adjust R64 for a 100 ns pulse width.

5) Darken the array, monitor J1-1, and adjust R4 (put on the component side of the array board) so that the video signal is approximately centered at -5 V DC. Saturate the array, and readjust R4, if necessary, so no signal or switching spike is more negative than -8 V DC. Do not over-saturate.

6) Monitor P2-N. The video output will be a sample-and-hold boxcar signal.

7) Darken the array and adjust R36 until the video signal is centered around the blanking level. (Blanking is clamped at zero.)

8) Adjust R11 until optimum performance is observed on the video. Optimum adjustment of R11 results in a balance of maximum video output, minimum switching spikes, and fixed pattern tracking from dark to 90% of saturation.

9) With the array in the dark, readjust R36 if necessary to bring the video level with blanking.

SPECIFICATIONS

ELECTRICAL CHARACTERISTICS (25°C)

	Min	Typ	Max	Units
[1]Positive Supply Voltage V_p	+4.5	+5	+5.5	volts
Negative Supply Voltage V_n	-10.5	-10	-9.5	volts
Clock Voltage Low V_{cl}	-10.5	0	+1	volts
Clock Voltage High V_{ch}	V_p-1	+5	V_p	volts
Start Voltage Low V_{sl}	-10.5	0	+1	volts
Start Voltage High V_{sh}	V_p-1	+5	V_p	volts
Clock Pulse Width	0.2	—	—	usec
Start Pulse Width		See Fig. 7		
Clock Frequency f_c	—	—	1	MHz
Integration Time t_i	—	—	30	msec
[2]Clock Input Capacitance C_c	—	5	—	pF
[2]Start Input Capacitance C_s	—	5	—	pF
[2]Video Line Capacitance C_v				
RL-1024G	—	40	—	pF
RL-512G	—	20	—	pF
RL-256G	—	10	—	pF
RL-128G	—	5	—	pF
End-of-Scan Output Resistance	—	5	—	Kohm
D-C Power Dissipation	—	45	—	mwatts

ELECTRO-OPTICAL CHARACTERISTICS (25°C)

	Min	Typ	Max	Units
Diode Center-to-Center Spacing	—	25	—	μm
Diode Aperture Width	—	26	—	μm
[3]Photodiode Sensitivity	—	2.5	—	pA/μwatt/cm²
[3]Non-uniformity of Sensitivity				
RL-128G	—	4	8	±%
RL-256G	—	4	8	±%
RL-512G	—	5	10	±%
RL-1024G	—	7	14	±%
[3]Saturation Exposure	—	1.3	—	μjoules/cm²
Saturation Charge	—	3.2	—	pcoul

NOTES:
1. No terminal should ever be allowed to go more positive than V_p.
2. Measured with nominal power supply voltages.
3. Measured using light source of Fig. 4.

(From Reticon Corp.)
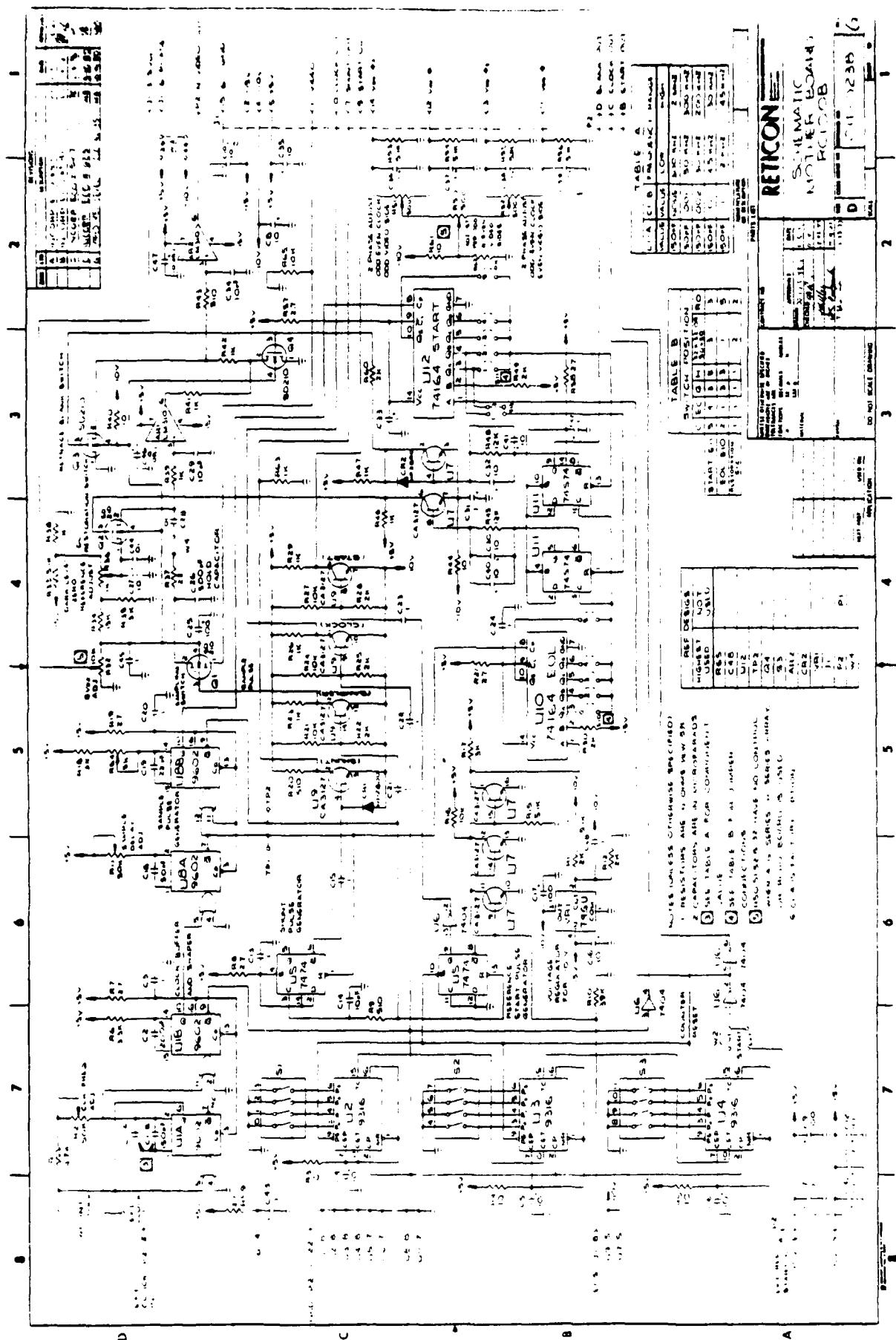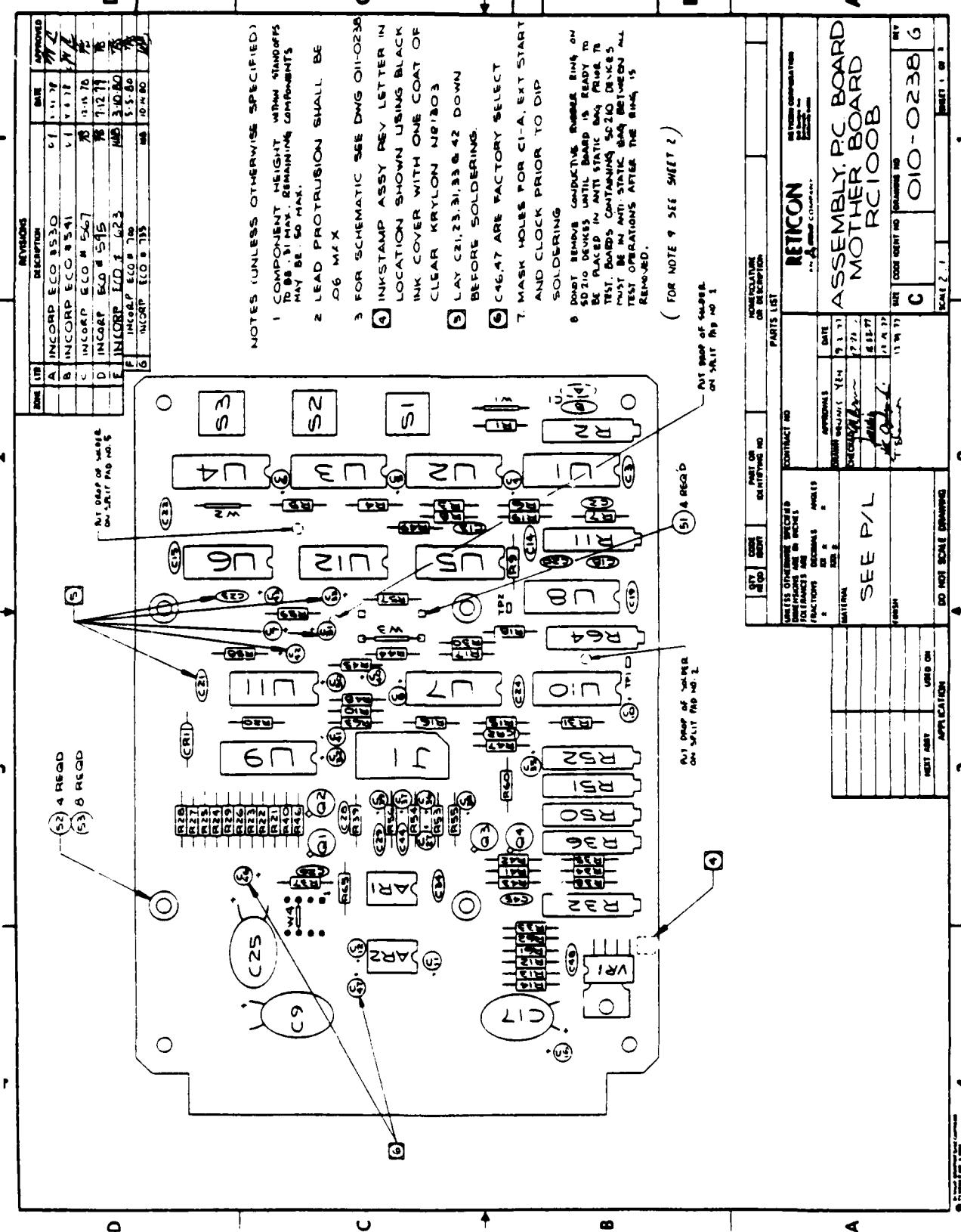
(From Reticon Corp.)

96

NOTES (UNLESS OTHERWISE SPECIFIED)

1. COMPONENT HEIGHT WITHIN STANDOFFS TO BE .31 MAX. REMAINING COMPONENTS MAY BE .50 MAX.

2. LEAD PROTRUSION SHALL BE .06 MAX

3. FOR SCHEMATIC SEE DWG 011-0238

4. INKSTAMP ASSY REV LETTER IN LOCATION SHOWN USING BLACK INK. COVER WITH ONE COAT OF CLEAR KRYLON Nº1303

5. LAY C21,23,31,33 & 42 DOWN BEFORE SOLDERING.

6. C46,47 ARE FACTORY SELECT

7. MASK HOLES FOR C1-A, EXT START AND CLOCK PRIOR TO DIP SOLDERING.

8. DON'T REMOVE CONDUCTIVE RUBBER RING ON SD210 DEVICES UNTIL BOARD IS READY TO BE PLACED IN ANTI STATIC BAG PRIOR TO TEST. BOARDS CONTAINING SD210 DEVICES MUST BE IN ANTI STATIC BAG BETWEEN ALL TEST OPERATIONS AFTER THE RING IS REMOVED.

(FOR NOTE 9 SEE SHEET 2)

PUT DROP OF SOLDER ON SPLIT PAD NO. 1

PUT DROP OF SOLDER ON SPLIT PAD NO. 5

PUT DROP OF SOLDER ON SPLIT PAD NO. 2

(52) 4 REQ'D
(53) 8 REQ'D

(51) 4 REQ'D

(From Reticon Corp.)

97

2 of 2
AD
A118156

END
DATE
FILMED
09-82
DTIC

APPENDIX B

SCHEMATIC   AND CALIBRATION PROCEDURE FOR THE ADAC 1012 A/D CONVERTER
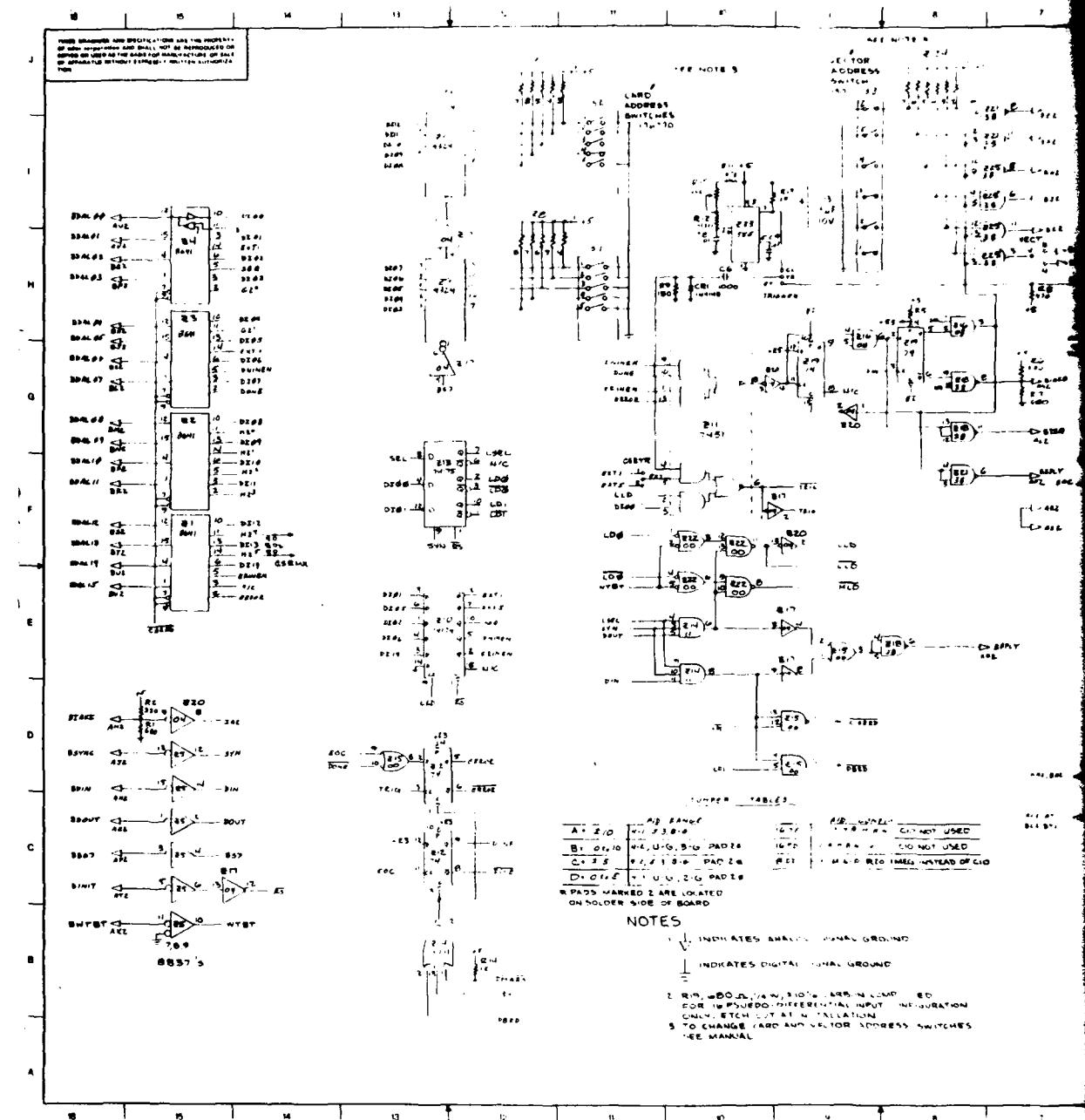
(From ADAC Corp.)
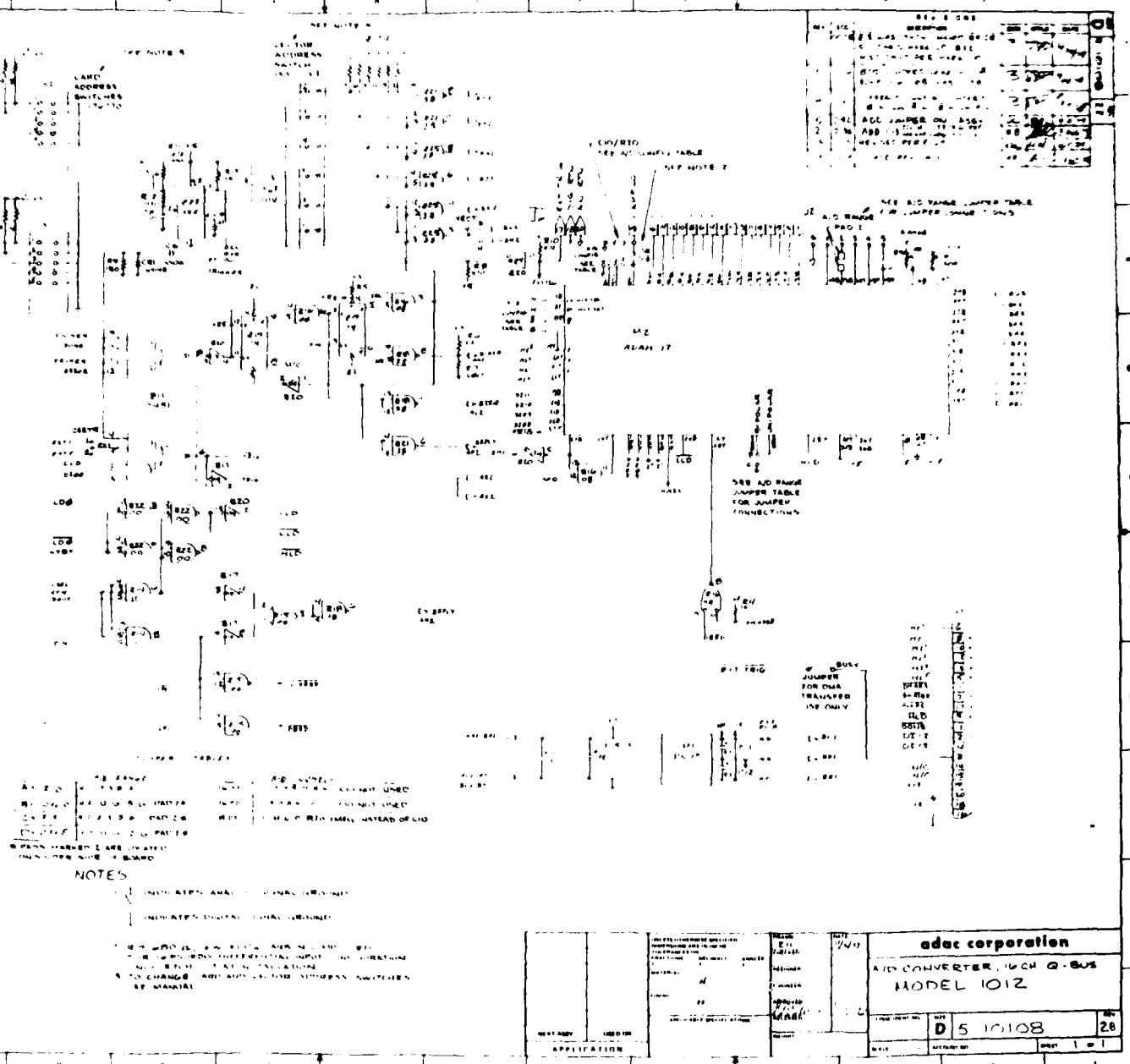
(From ADAC Corp.)

CALIBRATION PROCEDURE FOR THE ADAC 1012 A/D CONVERTER

1) Offset Adjustment

With the A/D board in the backplane of the LSI-11, apply the precise voltage shown below to any channel according to the range that has been jumpered on the board. Force a conversion through ODT and open the output buffer. The buffer should contain the code shown below. If not, adjust the Offset until the least significant bit of the code alternates between 1 and 0.

RANGE	INPUT	CODE
-10 V to + 10 V	+9.9976 V	
0 V to + 10 V	+0.0012 V	000000/1 UNIPOLAR
- 5 V to + 5 V	-4.9988 V	004000/1 BIPOLAR
0 V to + 5 V	+0.0006 V	

2) Range Adjustment

After the Offset has been adjusted, the range may be adjusted. Follow the same procedure outlined above, except this time use the values given below and make adjustments with the Range pot on the board.

RANGE	INPUT	CODE
-10 V to +10 V	+9.9927 V	
0 V to +10 V	+9.9963 V	7776/7 UNIPOLAR
- 5 V to + 5 V	+4.9963 V	3776/7 BIPOLAR
0 V to + 5 V	+4.9982 V	

APPENDIX C

SCHEMATICS FOR THE ADAC 1620 DMA

(From ADAC Corp.)

CONTROL LOGIC

adac corporation

SCHEMATIC
MODEL 1620 DMA

| | D | S-10156 |

(From ADAC Corp.)

(From ADAC Corp.)

SCHEMATIC
MODEL 1620 DMA

adac corporation

D 5-10156

DATA PATHS
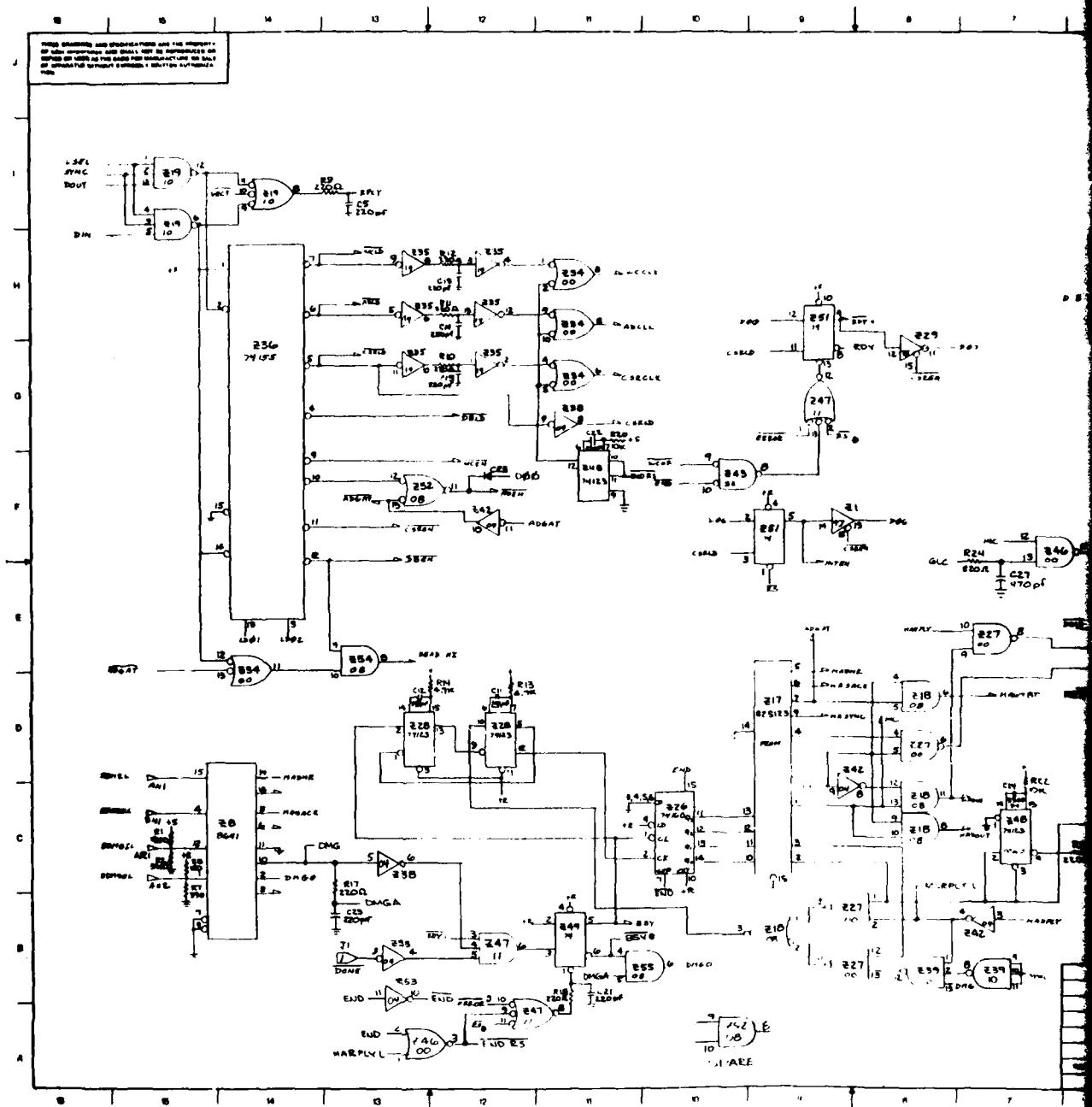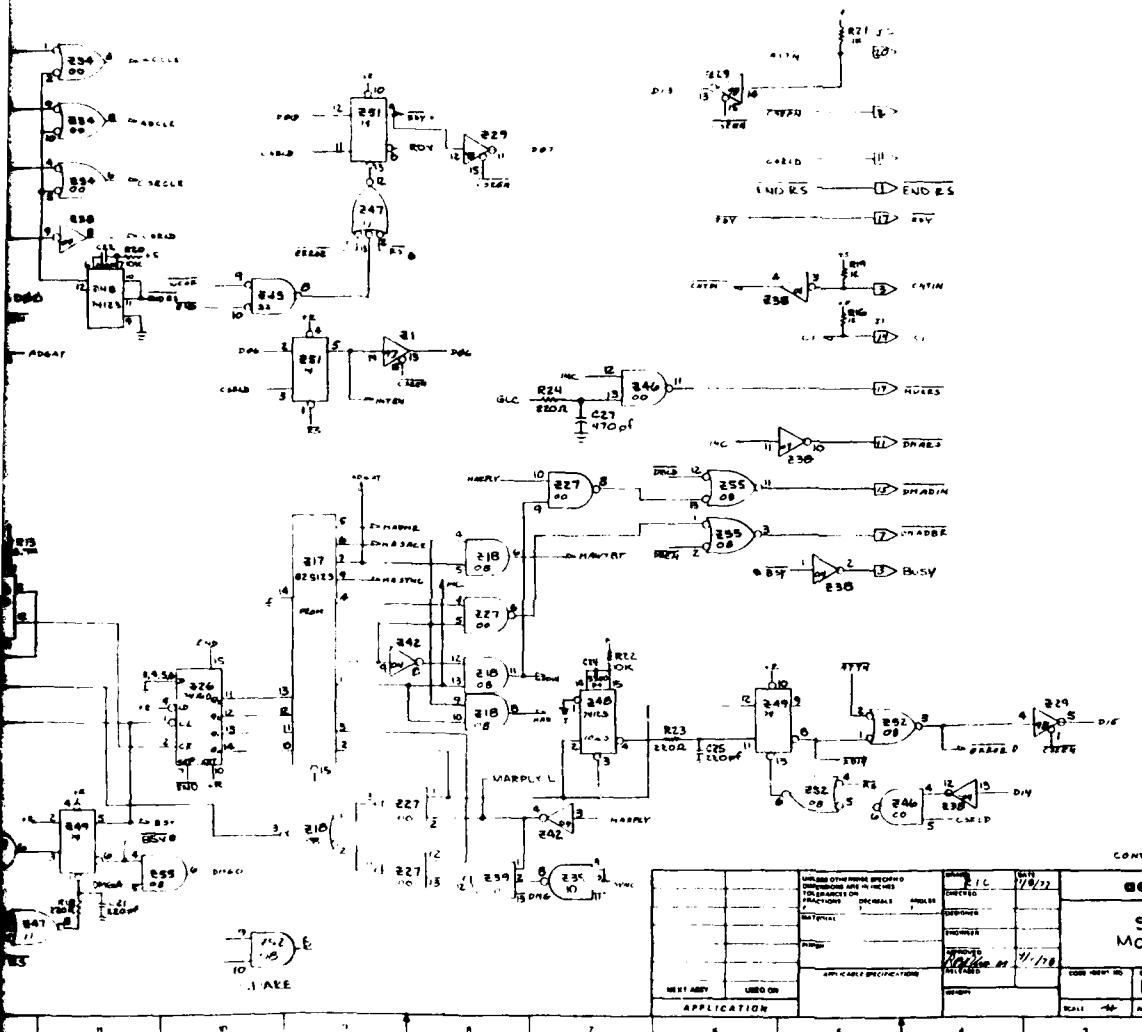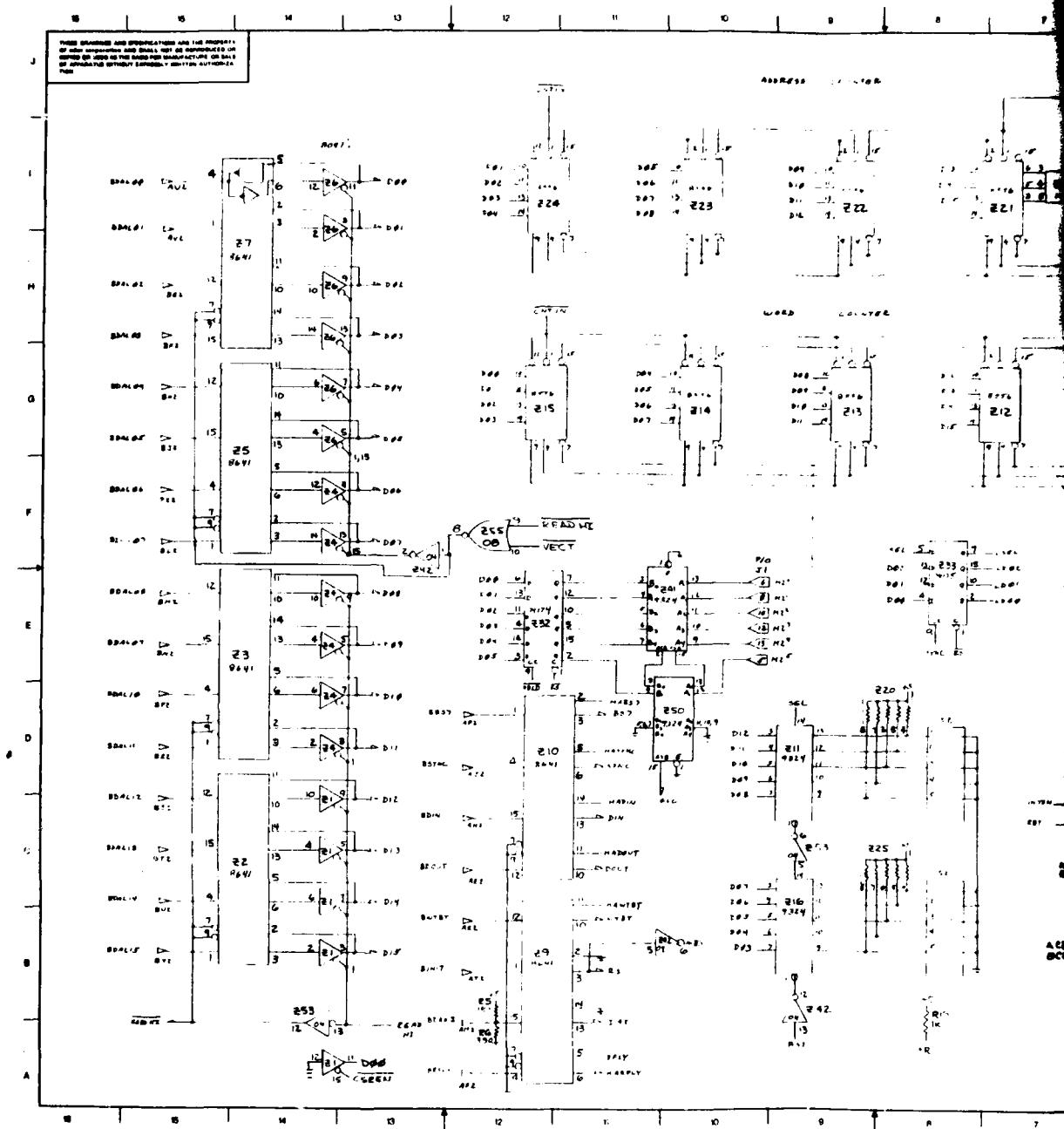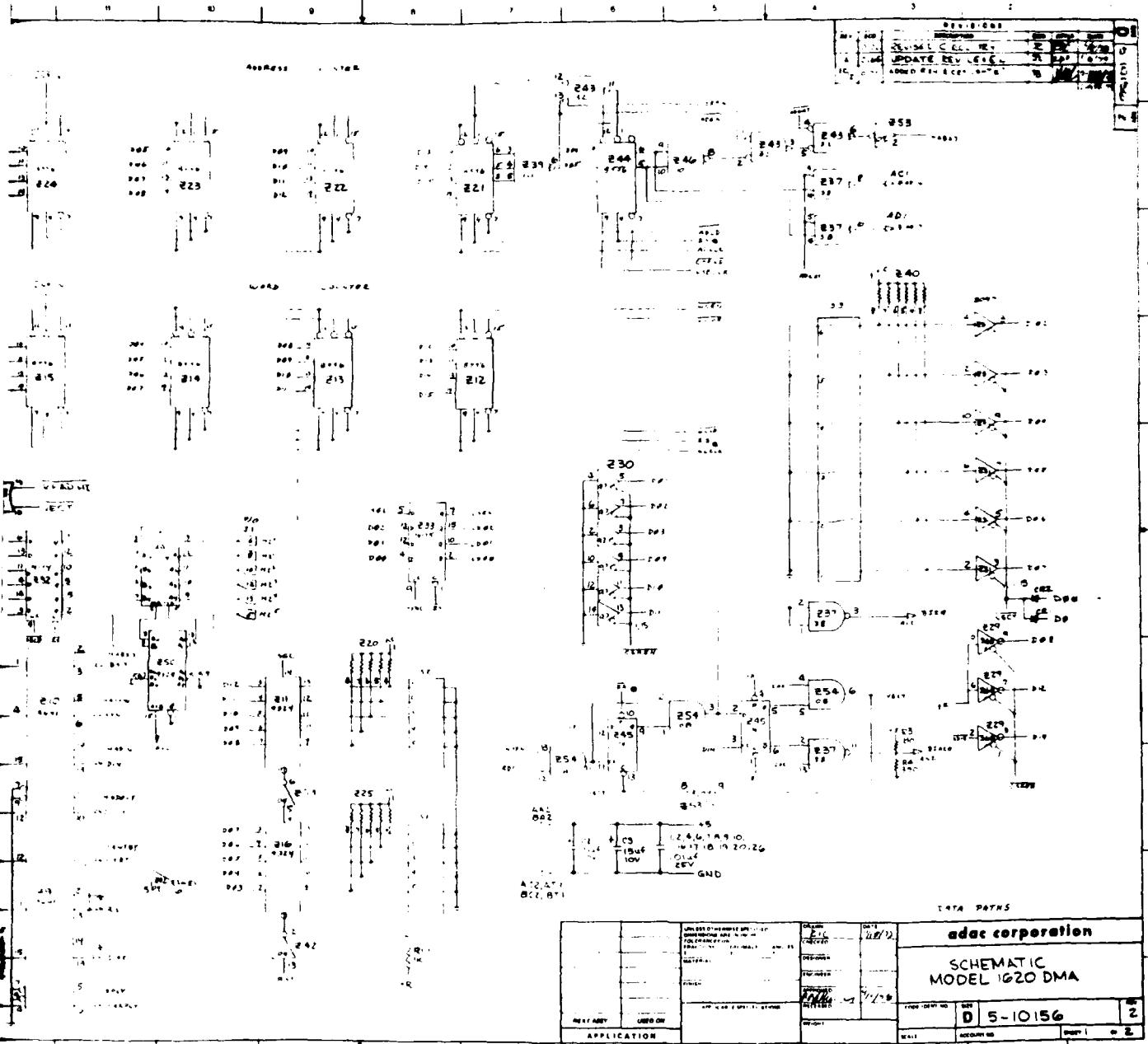
APPENDIX D

THE MACRO PROGRAM FOR THE WQM

```
    1                                              .TITLE  INIT.MAC
    2                                              .GLOBL  DMAIT
    3 000000   105737   172414          DMAIT:     TSTB    @#172414
;IS DMA BUSY?
    4 000004   100375                              BPL     DMAIT
;IF YES WAIT.
    5 000006   012737   176000   172410            MOV     #176000,@#172410
;SET WORD COUNT TO 1024 ON DMA.
    6 000014   012737   000000'  172412            MOV     #TOT,@#172412
;SET MEMORY ADDRESS TO DATA ARRAY ON DMA.
    7 000022   012737   000001   172414            MOV     #1,@#172414
;ENABLE DMA.
    8 000030   012737   000001   172416            MOV     #1,@#172416
;SET MUX COMPARISON REGISTER TO ONE      CHANNEL ON DMA.
    9 000036   012737   000032   177000            MOV     #32,@#177000
;SET UNITY GAIN,EXTERNAL ENABLE, AND     CHANNEL 0 ON A/D.
   10 000044   012737   000001   167772            MOV     #1,@#167772
;ENABLE SYNCHRONIZATION CIRCUITRY/ START SCAN.
   11 000052   105737   172414          1$:        TSTB    @#172414
;IS DMA BUSY?
   12 000056   100375                              BPL     1$
;IF YES, WAIT.
   13 000060   005737   177002                     TST     @#177002
;CLEAR A/D DATA BUFFER.
   14 000064   012737   000000   167772            MOV     #0,@#167772
;DISABLE SYNCHRONIZATION CIRCUITRY.
   15 000072   012737   000000   172414            MOV     #0,@#172414
;DISABLE DMA.
   16 000100   012737   000431   177000            MOV     #431,@#177000
;SET UNITY GAIN, CHANNEL 1, AND START    CONVERSION ON A/D.
   17 000106   105737   177000          LP1:       TSTB    @#177000
;IS CONVERSION DONE?
   18 000112   100375                              BPL     LP1
;IF NOT WAIT.
   19 000114   012701   000020'                    MOV     #TOT+16.,R1
;SET R1 TO NINTH WORD IN DATA ARRAY TOT.
   20 000120   013721   177002                     MOV     @#177002,(R1)+
;STORE VOLTAGE FROM A/D DATA BUFFER      AND INCREMENT LOCATION IN TOT.
   21 000124   012737   001031   177000            MOV     #1031,@#177000
;SET UNITY GAIN, CHANNEL 2, AND START    CONVERSION ON A/D.
   22 000132   105737   177000          LP2:       TSTB    @#177000
;IS CONVERSION DONE YET?
```

112

```
    23 000136  100375                              BPL     LP2
;IF NOT WAIT.
    24 000140  013721  177002                      MOV     @#177002,(R1)+
;STORE CURRENT FROM A/D DATA BUFFER     AND INCREMENT LOCATION IN TOT.
    25 000144. 012737  001431  177000              MOV     #1431,@#177000
;SET UNITY GAIN, CHANNEL 3, AND START       CONVERSION ON A/D.
    26 000152  105737  177000          LP3:        TSTB    @#177000
;IS CONVERSION DONE YET?
    27 000156  100375                              BPL     LP3
;IF NOT, WAIT.
    28 000160  013711  177002                      MOV     @#177002,(R1)
;STORE TRAVEL SPEED FROM A/D DATA BUFFER INTO TOT.
    29 000164  000207                  END1:       RTS     PC
;RETURN FROM SUBROUTINE.
    30 000000                                      .PSECT  TOT,RW,D,GBL,REL
.OVR    ;MAKE DATA ARRAY TOT READ/WRITE
    31
;DIRECT ACCESS,GLOBAL
    32
;RELOCATABLE,AND OVERLAYED.
    33 000000                          TOT:        .BLKW   1024.
;DATA ARRAY.
    34         000000'                              .END    DWAIT
;END OF PROGRAM
```

INIT.MAC   MACRO V03.02 00:37:30 PAGE 1-1
SYMBOL TABLE

```
DWAIT   000000RG            LP1     000106R            LP2     000132R
LP3     000152R            TOT     000000R     002
END1    000164R

. ABS.  000000     000
        000166     001
TOT     004000     002
ERRORS DETECTED:  0

VIRTUAL MEMORY USED: 299 WORDS  ( 2 PAGES)
DYNAMIC MEMORY AVAILABLE FOR  57 PAGES
DK:INIT,DK:INIT=DK:INIT
```

APPENDIX E

THE FORTRAN PROGRAM FOR THE WQM

```
FORTRAN IV        V02.04

        C       PROGRAM AQSPEC
        C       WRITTEN BY: MICHAEL E. NORRIS
        C       300 E.E.R.L.
        C       UNIVERSITY OF ILLINOIS?
        C       URBANA,ILLNOIS  61801
        C
        C
        C
        C       AQSPEC IS A FORTRAN PROGRAM CREATED TO ACQUIRE
        C       PARAMETERS ASSOCIATED WITH WELDS.  USING A
        C       SPECTROMETER AND OTHER HARDWARE IT GATHERS
        C       SPECTRAL AVERAGES, WELD CURRENT, VOLTAGE,
        C       AND TRAVEL SPEED.  IT WAS DEVELOPED UNDER A
        C       CONTRACT WITH THE ARMY CORPS OF ENGINEERS,
        C       CONSTUCTION ENGINEERING RESEARCH LABS,
        C       CHAMPAIGN, ILLINOIS.
        C
        C
        C       DBLK CONTAINS THE RADIX 50 REPRESENTATION OF THE DEVICE
        C       AND FILE SPECIFICATION. AVSCAN IS THE NUMBER OF
        C       SCANS TO BE AVERAGED.
        C
  0001          INTEGER*2   DBLK(4),AVSCAN
        C
        C       LBLK CONTAINS THE ASCII REPRESENTATION OF THE FILE
        C       NAME TO BE STORED ON A FLOPPY DISK.
        C
  0002          BYTE        LBLK(6)
        C
        C       JTIME WILL BE USED TO STORE THE TIME IN TICKS.
        C
  0003          INTEGER*4   JTIME
        C
        C       NA WILL SERVE AS AN ACCUMULATOR FOR AVERAGING SPECTRAL SCANS
        C
        C
  0004          DIMENSION NA(1024)
        C
        C       IDNAM CONTAINS THE RADIX 50 REPRESENTATION OF
        C       THE   DISK DEVICE HANDLER.
        C
  0005          DATA        IDNAM/2RDY/
        C
        C       SET UP DEVICE AND FILE SPECIFICATION IN RADIX 50.
```

116

```
       C
0006        DATA       DBLK(1)/3RDY1/,DBLK(4)/3RDAT/
       C
       C   SET UP DATA FILE AND OVERLAY IT WITH THE MACRO DATA FILE.
       C
0007        COMMON     /TOT/IA(1024)
       C
       C   QUERY THE USER AS FOLLOWS FOR DATA PARAMETERS
       C   GIVEN.
       C
0008   44   TYPE 45




FORTRAN IV      V02.04

0009   45   FORMAT(' DO YOU WISH TO LOOK AT AN OLD FILE?')
0010        TYPE 46
0011   46   FORMAT(' TYPE Y FOR YES, N FOR NO')
0012        ACCEPT 47,LKUP
0013   47   FORMAT(A1)
0014        IF(LKUP.EQ.'Y'.OR.LKUP.EQ.'N') GO TO 49
0016        TYPE 152
0017        GO TO 44
0018   49   IF(LKUP.EQ.'Y')GO TO 465
0020   50   TYPE 60
0021   60   FORMAT(' DO YOU WISH TO TAKE A SINGLE OR AVERAGE SCAN?')
0022        TYPE 80
0023   80   FORMAT(' TYPE S OR A')
0024        ACCEPT 100,SCAN
0025   100  FORMAT(A1)
0026        IF(SCAN.EQ.'S') GO TO 180
0028        IF(SCAN.EQ.'A') GO TO 120
0030   101  TYPE 110
0031   110  FORMAT(' ILLEGAL CHARACTER')
0032        GO TO 50
0033   120  TYPE 130
0034   130  FORMAT(' HOW MANY SPECTRA ARE TO BE AVERAGED?')
0035        TYPE 140
0036   140  FORMAT(' TYPE A NUMBER BETWEEN ONE AND NINE')
0037        ACCEPT 150,AVSCAN
0038   150  FORMAT(I2)
```

117

```
0039          IF(AVSCAN.LT.9.AND.AVSCAN.GT.0) GO TO 151
0041          TYPE 152
0042    152   FORMAT(' INVALID CHARACTERS.')
0043          GO TO 120
0044    151   TYPE 155
0045    155   FORMAT(' HOW MANY SCANS ARE TO BE TAKEN?')
0046          TYPE 157
0047    157   FORMAT(' TYPE UP TO A THREE DIGIT NUMBER.')
0048          ACCEPT 156,IBLONO
0049          IF(IBLONO.GT.0.AND.IBLONO.LT.200) GO TO 158
0051          TYPE 152
0052          GO TO 151
        C
        C     ADJUST IBLONO TO REFLECT BLOCKS RATHER THAN SCANS.
        C
0053    158   IBLONO=IBLONO*4
0054    156   FORMAT(I3)
0055          TYPE 160
0056    160   FORMAT(' ENTER A SIX CHARACTER FILE NAME HERE:')
0057          ACCEPT      170,(LBLK(J),J=1,6)
0058    170   FORMAT(6A1)
        C
        C     CONVERT FILE NAME FROM ASCII TO RADIX 50 AND PLACE IN
        C     DEVICE AND FILE SPECIFICATION.
        C
0059          CALL      IRAD50(6,LBLK,DBLK(2))
        C
        C     OBTAIN FLOPPY DISK HANDLER AND CHECK FOR AN ERROR.
```

FORTRAN IV   V02.04

```
        C
0060          IF(IFETCH(IDNAM) .NE. 0) STOP 'FETCH ERROR'
        C
        C     ALLOCATE A CHANNEL FOR DATA TRANSFER FROM HARD
        C     MEMORY TO FLOPPY DISK AND CHECK FOR AN ERROR.
        C
0062          ICHAN=IGETC()
0063          IF(ICHAN.LT.0) STOP 'CHANNEL ERR1'
        C
```

118

```
          C         GET THE FLOPPY DISK AREA, READY IT FOR WRITING,
          C         AND CHECK FOR AN ERROR.
          C
0065                IF(IENTER(ICHAN,DBLK,0) .LT. 0) STOP 'ENTER ERR'
0067      174       TYPE 175
0068      175        FORMAT(' AT THIS TIME THE SYSTEM IS READY')
0069                TYPE 176
0070      176        FORMAT(' TYPE R TO START RUN OR A TO ABORT.')
          C
          C         DISABLE KEYBOARD INTERRUPT UNTIL DATA TRANSFER
          C         HAS BEEN MADE.
          C
0071                CALL IPOKE('44,'10100.OR.IPEEK('44))
          C
          C         RESET BLOCK COUNTER.
          C
0072      201       KLOG=0
0073      202       ACCEPT 177,KEY
0074      177       FORMAT(A1)
0075      178        IF(KEY.EQ.'R') GO TO 300
0077                IF (KEY .EQ. 'A') GO TO 590
0079                GO TO 202
          C
          C         RESET THE DATA BUFFER.
          C
0080      300       DO 299 K=1,1024
0081      299       NA(K)=0
          C
          C         CONDUCT AVSCAN NUMBER OF SCANS SUCCESSIVELY
          C         ADDING THE DATA IN ARRAY NA.
          C
0082                DO 302 J=1,AVSCAN
          C
          C         CALL MACRO SUBROUTINE TO INITIATE SPECTRAL SCAN AND
          C         ACQUISITION OF VOLTAGE, CURRENT, AND TRAVEL SPEED.
          C
0083                CALL OMAIT
          C
          C         ADD SUCCESSIVE SCANS.
          C
0084                DO 301 I=7,1024
0085      301       NA(I)=NA(I)+IA(I)
0086      302       CONTINUE
          C
          C         GET TIME IN TICKS PAST MIDNIGHT.
```

```
FORTRAN IV      V02.04

      C
0087        CALL      GTIM(JTIME)
      C
      C     CONVERT THE TICKS FOUND ABOVE INTO HOURS, MINUTES,
      C     SECONDS, AND TICKS.
      C
0088        CALL      CVTTIM(JTIME,NA(4),NA(5),NA(6),NA(8))
      C
      C     STORE THREE INTEGER VALUES CORRESPONDING TO THE
      C     MONTH, DAY, AND YEAR.
      C
0089        CALL      IDATE(NA(1),NA(2),NA(3))
      C
      C     STORE NUMBER OF SCANS AVERAGED.
      C
0090        NA(7)=AVSCAN
      C
      C     WRITE THE DATA ONTO THE FLOPPY DISK.  IF AN ERROR
      C     OCCURS, REPORT IT.
      C
0091        IF(IWRITW(1024,NA,KLOG,ICHAN).LT.0)STOP 'WRITE ERR1'
      C
      C     ADVANCE BLOCK NUMBER BY FOUR OR 1024 WORDS.
      C
0093        KLOG=KLOG+4
      C
      C     CHECK TO SEE IF THE NUMBER OF SCANS TAKEN (KLOG)
      C     EQUALS THE NUMBER DESIRED TO BE AQUIRED (IBLONO).
      C
0094        IF(KLOG.GE.IBLONO)GO TO 400
0096        GO TO 300
      C
      C     THE FOLLOWING CODE IS USED FOR CALIBRATION OF A
      C     SINGLE SCAN.
      C
      C     TAKE A SCAN.
      C
0097  180   CALL DMAIT
0098        DO 215 I=1,1024
```

```
        C
        C     CONVERT THE A/D VALUE TO ITS CORRESPONDING DECIMAL
        C     VALUE.
        C
0099  215    IA(I)=((4095-IA(I))+1)*4.88
        C
        C     TYPE OUT A SINGLE SCAN.
        C
0100         DO 220 I=0,1016,8
0101  220      TYPE #,(IA(I+J),J=1,8)
0102         GO TO 590
        C
        C     CLOSE OUT THE CHANNEL AND CLEAR THE BLOCK COUNT
        C
0103  400    CALL       CLOSEC(ICHAN)




FORTRAN IV      V02.04


        C
        C     RESTORE TERMINAL INTERRUPTS.
        C
0104         CALL       IPOKE('44,'167677 .AND. IPEEK('44))
0105  405      TYPE   410
0106  410      FORMAT(' DO YOU WISH TO SEE THE RESULTS?')
0107         ACCEPT 420,IANS
0108  420      FORMAT(A1)
0109         IF(IANS.EQ.'Y'.OR.IANS.EQ.'N') GO TO 421
0111         TYPE 152
0112         GO TO 405
0113  421    IF(IANS.EQ.'Y')GO TO 465
0115         GO TO 561
0116  465      TYPE 470
0117  470      FORMAT(' WHAT FILE CODE WORD DO YOU YOU WISH TO ACCESS?')
0118         TYPE 480
0119  480      FORMAT(' TYPE SIX CHARACTER CODE')
0120         ACCEPT 490,(LBLK(I),I=1,6)
0121  490    FORMAT(6A1)
0122  485    TYPE 481
0123  481    FORMAT(' TYPE A THREE DIGIT SCAN NUMBER')
0124         ACCEPT 491,KLOG
```

```
0125   491      FORMAT(I3)
       C
       C         ADJUST THE NUMBER OF SCANS TO REFLECT THE CORRESPONDING
       C         BLOCK VALUE.
       C
0126            KLOG=KLOG*4
       C
       C         CONVERT FILE NAME TO RAD50.
       C
0127            CALL          IRAD50(6,LBLK,DBLK(2))
       C
       C         OBTAIN FLOPPY DISK DEVICE HANDLER AND CHECK FOR AN ERROR.
       C
0129            IF(IFETCH(IDNAM).NE.0)STOP'FETCH ERR2'
       C
       C         ALLOCATE A CHANNEL FOR DATA TRANSFER.
       C
0130            ICHAN=IGETC()
       C
       C         CHECK FOR CHANNEL ALLOCATION ERROR.
       C
0131            IF (ICHAN.LT.0)STOP 'CHANNEL ERR2'
       C
       C         LOCATE DESIRED FILE ON FLOPPY DISK AND CHECK FOR AN ERROR.
       C
0133            IF(LOOKUP(ICHAN,DBLK).LT.0)STOP 'BAD LOOKUP'
       C
       C         READ FILE FROM FLOPPY AND STORE IT IN NA AND CHECK FOR AN ER
ROR.
       C
0135            IF(IREADW(1024,NA,KLOG,ICHAN).LT.0)STOP 'READ ERR'
       C
       C         CLOSE OUT THE CHANNEL.



FORTRAN IV      V02.04

       C
0137            CALL CLOSEC(ICHAN)
0138            KLOG=0
       C
```

```
        C       PRINT OUT THE DATA READ FROM THE FLOPPY.
        C
0139            TYPE 520,(LBLK(I),I=1,6)
0140    520     FORMAT(' FILENAME:',6A1)
0141            TYPE 530,NA(1),NA(2),NA(3)
0142    530     FORMAT(' DATE:',I2,' -',I2,' -',I2)
0143            TYPE 540,NA(4),NA(5),NA(6),NA(8)
0144    540     FORMAT(' TIME=',I2,' :',I2,' :',I2,' :',I2)
        C
        C       CONVERT SPECTRAL BINARY VALUES TO CORRESPONDING
        C       DECIMAL VALUES.
        C
0145            DO 547,I=12,1024
0146    547     NA(I)=((4095-(NA(I)/NA(7)))+1)*4.88
0147            DO 548 I=9,11
0148    548     NA(I)=((NA(I)/NA(7))+1)*4.88
        C
        C       CONVERT VOLTAGE,CURRENT, AND TRAVEL SPEED
        C       BINARY VALUES TO CORRESPONDING DECIMAL VALUES
        C       AND PRINT THE DATA.
        C
0149            TYPE        1000,NA(7)
0150    1000    FORMAT(' AVERAGE NO. OF SCANS=',I2)
0151            TYPE        1001,NA(9)
0152    1001    FORMAT(' VOLTAGE=',I5)
0153            TYPE        1002,NA(10)
0154    1002    FORMAT(' CURRENT=',I5)
0155            TYPE        1003,NA(11)
0156    1003    FORMAT(' TRAVEL SPEED=',I5)
0157            TYPE        *,(NA(I),I=12,16)
0158            DO 550 I=16,1016,8
0159    550     TYPE *, (NA(I+J),J=1,8)
        C
        C       QUERY THE USER ABOUT THE COURSE OF ACTION
        C       TO BE TAKEN AS FOLLOWS:
        C
0160    551     TYPE 555
0161    555     FORMAT(' DO YOU WISH TO SEE ANOTHER SCAN?')
0162            TYPE 556
0163    556     FORMAT(' TYPE Y FOR YES, N FOR NO')
0164            ACCEPT 557,KANS
0165    557     FORMAT(A1)
0156            IF(KANS.EQ.'Y'.OR.KANS.EQ.'N') GO TO 559
0158            TYPE 152
0169            GO TO 551
0170    559     IF(KANS.EQ.'Y')GO TO 485
0172    561     TYPE 560
```

123

```
0173  560     FORMAT(' DO YOU WISH TO SEE ANOTHER FILE?')
0174          TYPE 570
0175  570     FORMAT(' TYPE Y FOR YES, N FOR NO')
```

FORTRAN IV   V02.04

```
0176          ACCEPT 580,JANS
0177  580      FORMAT(A1)
0178          IF(JANS.EQ.'Y'.OR.JANS.EQ.'N') GO TO 589
0180          TYPE 152
0181          GO TO 561
0182  589     IF(JANS.EQ.'Y') GO TO 465
0184  590      TYPE 600
0185  600      FORMAT(' DO YOU WISH TO TAKE ANOTHER SCAN?')
0186          TYPE 610
0187  610      FORMAT(' Y FOR YES, N FOR NO')
0188          ACCEPT 620,NANS
0189  620      FORMAT(A1)
0190          IF(NANS.EQ.'Y'.OR.NANS.EQ.'N') GO TO 629
0192          TYPE 152
0193          GO TO 590?
*****  I
0194  629     IF(NANS.EQ.'Y') GO TO 50
0196  630     STOP
0197          END
```

FORTRAN IV   Storage Map for Program Unit .MAIN.

Local Variables, .PSECT $DATA, Size = 004112 (1061. words)

Name	Type	Offset	Name	Type	Offset	Name	Type	Offset
AVSCAN	I*2	004044	I	I*2	004074	IANS	I*2	004076
IBLONO	I*2	004060	ICHAN	I*2	004064	IDNAM	I*2	004016

124

```
J         I*2   004062     JANS    I*2   004102     JTIME   I*4   004046
K         I*2   004072,    KANS    I*2   004100     KEY     I*2   004070
KLOG      I*2   004066     LKUP    I*2   004052     NANS    I*2   004104
SCAN      R*4   004054


COMMON Block /TOT   /, Size = 004000 ( 1024. words)

Name  Type  Offset    Name   Type  Offset     Name   Type  Offset
IA    I*2   000000

Local and COMMON Arrays:

Name      Type      Section Offset    ------Size------ Dimensions
DBLK      I*2       $DATA   000000    000010 (    4.) (4)
IA        I*2       TOT     000000    004000 ( 1024.) (1024)
LBLK      L*1       $DATA   000010    000006 (    3.) (6)
NA        I*2       $DATA   000016    004000 ( 1024.) (1024)

Subroutines, Functions, Statement and Processor-Defined Functions:

Name    Type   Name    Type   Name    Type   Name    Type   Name    Type
CLOSEC  R*4    CVTTIM  R*4    DWAIT   R*4    GTIM    R*4    IDATE   I*2
IENTER  I*2    IFETCH  I*2    IGETC   I*2    IPEEK   I*2    IPOKE   I*2
IRAD50  I*2    IREADW  I*2    IWRITW  I*2    LOOKUP  I*2
```

125

APPENDIX F

AN EXAMPLE OF THE DATA OBTAINED FROM THE WQM
WHEN DISPLAYED ON THE DECWRITER LA-120

```
FILENAME:LSRSS2
DATE: 9 -24 -81
TIME=16 :38 : 7 :42
AVERAGE NO. OF SCANS= 2
VOLTAGE=19051
CURRENT   34
TRAVEL SPEED=19905
```

297	317	307	292	278			
287	273	263	263	263	258	253	224
268	253	248	239	258	244	234	229
239	224	229	209	234	219	219	204
219	209	209	204	209	214	200	195
214	209	209	200	204	200	190	190
195	190	185	180	185	200	185	170
185	190	180	185	190	170	195	170
200	180	190	161	180	175	175	161
180	170	180	146	175	165	151	151
175	161	165	161	151	170	165	156
165	165	161	141	156	161	146	136
165	146	141	141	146	141	151	146
151	151	146	131	146	136	151	122
156	136	131	126	141	126	141	136
156	141	136	117	136	131	136	126
146	136	122	136	126	141	126	117
131	122	136	122	131	141	126	122
131	122	112	102	117	117	122	112
126	112	117	122	131	117	131	97
122	122	112	92	136	117	126	102
122	117	97	97	117	112	112	102
122	131	122	117	112	126	122	97
126	117	102	107	126	131	112	107
126	102	102	107	122	126	126	112
146	141	141	126	146	141	136	131
151	151	165	156	175	175	200	180
200	200	195	204	268	312	302	292
312	287	244	219	234	248	273	253
268	278	302	317	361	356	341	336
429	458	497	502	497	448	429	390
380	361	370	351	351	341	390	395
395	429	414	400	473	590	697	561
444	424	414	356	409	473	453	390
375	366	390	414	434	444	497	453
536	531	463	409	419	473	546	546
566	610	785	946	795	692	639	468
541	692	580	429	492	600	678	692
687	595	736	732	575	629	771	624

575	561	585	668	624	522	458	419
473	522	497	439	478	497	551	653
727	683	756	751	946	1478	1903	1424
1146	922	834	1029	1302	1171	1117	1156
1000	1146	1224	1093	951	917	1019	985
1098	1293	1185	863	727	653	629	575
585	492	453	448	444	409	463	483
570	717	722	658	590	639	605	478
473	468	468	444	473	507	502	439
405	370	385	395	473	649	805	614
473	414	395	375	414	409	405	390
409	390	409	380	370	331	317	307
351	375	434	683	1044	814	448	351
380	370	351	346	380	375	395	424
419	385	390	356	351	326	322	331
366	385	370	336	331	317	326	336
361	331	336	336	346	317	331	331
405	463	453	385	414	370	351	331
356	375	400	336	336	326	331	302
322	322	331	326	346	322	302	287
317	307	326	326	326	297	292	287
312	312	322	312	326	312	322	292
326	326	341	341	390	390	405	429
434	405	429	463	497	409	390	395
468	473	414	356	370	351	326	302
322	326	317	307	322	317	322	322
361	351	351	361	400	414	400	361
356	346	341	322	351	336	370	361
385	380	385	361	419	453	419	370
458	536	527	395	390	405	463	536
517	400	405	414	434	400	356	312
346	356	361	331	351	326	317	317
317	307	326	322	341	312	322	322
336	326	341	307	356	356	341	307
312	312	302	292	302	263	278	263
283	292	302	312	336	375	375	302
287	287	283	297	317	283	278	283
297	273	283	283	307	292	268	253
258	263	273	244	283	278	273	297
351	322	312	263	287	263	278	253
268	273	287	278	312	278	283	263
292	273	263	244	268	258	258	239
248	263	273	253	278	278	268	268
283	263	248	244	263	258	253	244
258	253	283	283	322	322	297	273
283	253	258	239	258	248	239	224
239	229	224	219	239	229	229	209

229	214	229	214	229	224	204	209
224	224	229	239	283	292	278	244
229	229	214	204	229	214	209	195
209	219	209	195	219	204	200	200
219	195	200	180	209	200	200	185
224	209	195	185	214	204	195	180
204	204	209	195	204	204	204	190
209	190	180	165	190	185	190	175
200	185	190	165	200	190	175	180
190	190	170	170	190	185	170	175
175	175	175	141	180	170	151	156
175	161	165	151	170	175	165	146
170	161	165	146	165	170	161	146
175	151	156	146	146	146	151	122
156	136	131	117	151	126	136	122
136	136	141	141	146	146	141	112
141	126	122	117	141	141	131	126
146	117	131	117	141	136	131	112
141	141	146	117	156	146	131	117
141	97	136	107	131	122	126	107
131	122	131	107	141	122	117	117
126	131	117	117	126	117	117	102
102	117	112	112	122	122	117	97
126	117	122	97	126	107	117	102
131	112	122	102	117	112	107	92
117	97	126	97	126	122	107	102
126	112	126	102	102	107	112	102
122	112	112	107	117	112	107	102
122	117	97	97	117	97	102	107
102	107	107	97	117	117	112	87
117	97	102	97	112	107	107	97
131	97	107	92	102	102	112	87
122	102	97	82	112	112	97	97
117	92	102	92	112	112	107	102
97	97	102	78	107	117	92	87
112	102	107	97	122	97	102	87
102	97	102	97	102	102	102	78
102	97	82	82	112	92	102	92
102	102	102	97	97	97	92	78
112	97	97	73	102	112	78	82
107	87	97	97	92	112	107	87

APPENDIX G

AN EXAMPLE OF CALIBRATION DATA FOR THE
SPECTROGRAPH TAKEN USING THE WQM

```
.RUN ADSPEC
DO YOU WISH TO LOOK AT AN OLD FILE?
TYPE Y FOR YES, N FOR NO
N
DO YOU WISH TO TAKE A SINGLE OR AVERAGE SCAN?
TYPE S OR A
S
     39      43     146     161     117      97     112      92
  19573   19602   19637     102     102     102      97      69
    107     112     102      82      97     102     112     102
    102      97      97      92     102     122     102     102
    117      97     112     102     102     107     102     107
    112     112      92      97     107      97     102      92
    102      97     102     102     102     102     122      87
    102      92      92      87      92      97     107      78
    107     107      87      87     112     102      92      82
    102     107     122      82      97      92     102     102
    122      97      87      92     102      87     107      97
     92     102      97      68      87      97      97      78
    107     107      82      87     117      92      97      92
    117      87      97      92     117     112      97      92
    112      97      97     102      97      97     117      82
     97     112     102      87      87     102     112      82
    102      92     107     102     107      97     102      82
    102      97      97      92      97      97     107      97
    122      97      92     102     102      87     107      87
     92     107      92      78      92     102     107      73
    107     112      87      97     112      92     102      87
    112      87      92      87     117     112      97      92
    122     102     102     107     102     102     122      92
    102     112      97      87      87     102     117      82
    102      92     102     107     117     107     102      82
    102      97     102     102     107      97     102     107
    122     102      92     102     112      92     117      92
     97     102     112      82      97     107     112      92
    117     112      92     102     122      92     107      92
    117      87     102      92     117     122     112     102
    122     102     102     107     102      97     112      92
    102     112      97      92      87     102     112      82
    102      97     102      97     107      97      97      82
    107      92      92      92     102      97     107     102
    122      97      87     107     102      87     107      72
     87     102      97      73      92      97      97      73
     97     107      87      92     107      82     107      87
```

132

107	68	92	87	112	112	92	92
122	92	92	97	97	97	112	82
97	112	92	82	92	102	112	73
102	87	107	92	112	97	97	82
107	87	92	92	107	107	97	73
102	97	97	73	107	107	87	97
112	87	107	102	112	87	97	87
117	112	97	102	122	97	87	97
102	87	107	92	97	107	97	73
87	102	97	73	107	107	87	97
117	87	102	87	112	87	92	87
112	112	92	92	122	92	102	102
102	97	112	82	97	112	97	82
102	102	112	78	102	92	102	97
117	107	102	82	102	92	97	92
112	117	97	73	112	102	107	78
107	107	87	97	117	87	107	107
141	87	97	92	117	112	102	102
112	102	92	102	102	92	117	92
97	117	102	82	92	107	112	87
112	107	112	97	112	107	112	102
112	112	102	102	92	107	112	82
112	107	97	82	97	102	122	107
112	102	117	87	112	117	97	92
122	97	102	102	102	92	102	92
112	87	97	97	92	92	87	87
112	112	97	87	87	97	87	82
112	92	112	82	97	87	92	92
92	102	102	73	102	97	97	82
92	92	102	97	92	92	92	92
97	122	92	97	122	87	107	97
97	102	107	82	87	102	102	92
87	97	97	73	107	102	82	87
112	107	82	78	97	107	112	82
112	122	92	73	107	92	82	97
102	87	102	82	87	87	97	92
92	112	107	73	107	107	92	97
107	112	87	87	112	112	112	92
112	112	92	87	122	97	102	102
97	92	112	87	97	92	102	102
102	97	92	92	122	112	102	92
102	92	97	92	112	97	97	92
122	122	97	78	112	102	87	92
112	87	102	97	97	87	112	102
102	112	112	82	117	117	92	102
107	112	87	97	112	112	122	92
117	122	102	92	122	102	102	107

102	97	122	87	97	97	117	112
102	102	97	102	122	107	102	97
102	102	92	87	112	97	97	97
122	122	102	78	112	97	82	87
102	82	102	92	82	87	97	97
87	102	112	73	112	112	82	97
107	112	82	87	107	112	112	87
112	112	97	87	122	97	97	102
102	92	112	87	97	87	107	102
92	97	87	97	107	107	92	92
102	97	87	87	107	102	122	87
92	107	102	97	92	107	112	73
112	112	92	97	122	97	92	87
107	112	122	92	117	122	97	73
112	97	87	92	102	87	102	97
87	87	102	92	87	107	107	73
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102	107	122	92	112	112	92	78
112	92	92	102	97	92	112	82
97	87	102	102	97	92	92	92
117	107	97	92	87	102	87	87
112	87	97	92	122	122	97	82
117	97	87	97	107	87	102	82
92	92	102	92	87	102	107	73
112	107	82	97	112	112	87	92
107	97	97	92	97	92	97	102
97	107	97	102	112	92	97	87
112	97	102	87	122	122	102	102
112	102	112	102	102	87	102	92
112	87	97	97	87	97	107	78
107	107	97	68	92	102	107	97
112	112	97	92	97	117	97	78
112	97	87	97	102	87	87	87
107	87	97	92	92	102	97	73
107	107	97	68	97	97	107	97
112	97	112	78	107	117	97	92
122	97	102	102	107	92	102	97
117	92	102	87	112	112	112	87
112	92	97	82	102	112	107	107
102	87	102	92	117	87	102	107
92	107	107	78	112	112	112	82
107	102	117	97	107	112	122	87
92	112	97	82	117	97	92	92
112	92	87	92	112	87	107	102

134

APPENDIX H

FLOPPY DISK FORMATTING AND INITIALIZATION

Inherent in the RT-11 System Software is a utility program called "Format." Any new floppy disk will be unformatted (note: formatting destroys data currently on a disk). To format a floppy disk for this system, type in on the LA-120, "R FORMAT." Then press the return button. The utility program will respond with a prompt that looks like this: *. Then, assuming the unformatted disk is in slot 1 and the system floppy disk is in slot 0, type "DY1:/Y." Then press return.

To initialize the floppy disk for file structuring (this will also destroy all existing files on the floppy disk), type in: "INITIALIZE/ BADBLOCKS DY1:." The system will respond with: "DY1: Init are you sure?." Type in "Y." The floppy disk will now be ready for data accumulation. Further information on these commands can be found in the RT-11 operator manuals.

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262

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64